

INHERITANCE OF AGRONOMIC CHARACTERS AND CERTAIN QUALITY  
FACTORS IN THE CROSS, KANRED X HARD FEDERATION

by

AUSTIN GERALD GOTH

B. S., University of Nebraska, 1929

---

A THESIS

submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE

KANSAS STATE AGRICULTURAL COLLEGE

1930

Docu-  
ment  
LD  
2668  
74  
1930  
G615  
C.2

## TABLE OF CONTENTS

	Page
INTRODUCTION .....	3
REVIEW OF LITERATURE .....	3
Agronomic Characters .....	3
Quality Factors .....	7
MATERIALS AND METHODS .....	9
Parental Varieties .....	9
EXPERIMENTAL RESULTS .....	17
Agronomic Characters .....	17
Earliness .....	17
Gold Resistance .....	25
Stiffness of Straw .....	30
Yield .....	36
Test Weight .....	48
Plumpness of Kernels .....	49
Summary of Agronomic Characters .....	59
Quality Factors .....	59
Flour Yield .....	59
Protein Content .....	67
Loaf Volume, Texture and Color .....	72
Gluten Quality .....	80
Viscosity .....	81
The Foster Gluten Test .....	86
Extensimeter Tests .....	89
SUMMARY AND CONCLUSIONS .....	93
ACKNOWLEDGMENTS .....	97
LITERATURE CITED .....	98

## INTRODUCTION

Agronomists and wheat growers realize that a winter wheat which is earlier, stiffer strawed and higher yielding than the standard varieties now grown in Kansas would be a valuable contribution. Improvement in these characters should result in the production of varieties better adapted to a wider range of conditions.

About ten years ago certain crosses were made which involved earliness, stiffness of straw, good quality, high yield, winterhardiness and other desirable characters. One of these was a cross between Hard Federation, a white Australian spring wheat, which is non-winterhardy, matures early and has stiff straw and Kanred, a high yielding, hardy, relatively late, hard, red, winter wheat, with weak straw. Some of the data obtained in studying this cross from the  $F_3$  to the  $F_6$  generation are presented in this thesis. Those data deal with agronomic characters and certain factors influencing milling and baking qualities.

## REVIEW OF LITERATURE

### Agronomic Characters

Quisenberry and Clark ( 15 ) state that the development of hardy strains of hard, red, winter wheat must be

associated with an increased acre yield. They studied the problem of increasing winterhardiness, yield, and improving quality by conducting an extensive crossing program, using very winterhardy varieties such as Odessa, Buffum, Minhardi, Minturki, et al and high quality hard wheats such as Turkey, Kharkof and Kanred.

Selections were made on the basis of winterhardiness, yield and quality. There was some evidence that the characters winterhardiness and late maturity are associated in inheritance.

The most promising strains have been increased to plot tests at two northern stations. One year's results indicate that some of the hybrid selections are promising for winterhardiness, high yield, and good milling and baking qualities.

Hayes and Aamodt ( 11 ), in a study of the inheritance of winterhardiness in winter x spring wheat crosses, concluded that in the  $F_1$  generation spring-habit of growth and low cold resistance are dominant over winter-growth habit and high cold resistance. In the  $F_4$  generation lines homozygous for winter and spring growth habit exhibited only small differences in winterhardiness. A high correlation was found between cold resistance and winter habit, although this correlation was not perfect. These results agree with Nilsson-Ehle's conclusion that winter resistance is inherited

in the same manner as other quantitative characters, being controlled by several Mendelian factors. Hayes and Garber, Akerman and other investigators have obtained evidence of transgressive segregation for winterhardiness.

Clark, Florell and Hooker ( 6 ) found that the average yield per plant of the  $F_2$  hybrids which they studied was between the yields of the parents. A few  $F_3$  strains in all classes studied were higher yielding than the parent check rows. Under the conditions of the test there was but slight tendency for yield to increase with increase in length of awns.

Transgressive segregation was noted in the study of the inheritance of kernel texture. Only a small number of  $F_2$  plants and  $F_3$  strains exceeded the best parental plants or rows in crude-protein content. Their results indicate that under some conditions yield and crude-protein content may be unassociated, or correlated positively as frequently as negatively.

Hayes, Immer and Bailey (12) made a statistical study of the inheritance of quality and concluded that neither protein content nor kernel texture was significantly or consistently related to loaf volume, as determined by the experimental baking methods used. There was some indication

of a slight positive relation between loaf volume, texture and color score of loaf, although the limits of this association were rather narrow. With wheats of diverse nature, kernel texture and protein content were not very highly associated with loaf volume as determined by experimental baking trials. The absence of a high positive relation in wheats of diverse nature indicates that protein determinations made during the segregating generations are of little value to the wheat breeder as a means of selecting high quality strains.

Clark and Quisenberry ( 7 ) found that the yields of hybrids were more variable than the yields of the parents. Yield and protein content were negatively correlated in both the  $F_2$  and  $F_3$  generations, but in neither case was the coefficient of correlation large enough to be of importance to the plant breeder.

It was found in this study that the intermediate or awnletted strains, in both  $F_2$  and  $F_3$ , significantly out-yielded the awned types. The awnletted and awned classes segregated close to a 3:1 ratio in the  $F_2$  generation.

The crude-protein content of  $F_2$  plants and  $F_3$  strains was positively correlated, the values of  $r$  being statistically significant and important. These authors suggest that selection of plants of high protein content in

the  $F_2$  generation may be used as a means of making progress in raising the crude-protein content through plant breeding methods. It is their opinion that yield is largely the result of the interaction of environment and the physiological and morphological characters of the plant.

#### Quality Factors

Shollenberger and Clark ( 20 ), in reporting their studies of the milling and baking qualities of American wheat varieties, recommend that, in order to satisfy the farmer, the miller and the baker, new wheats must yield more per acre and must also be of superior quality.

They also conclude that new and standard varieties differ greatly in their quality attributes. They are of the opinion that the effects of season, locality, rainfall, elevation, and soil type are of less importance than varietal differences.

Swanson ( 23 ) points out the diversity of application, in common use, of the meaning of quality in wheat. The wheat producer, the baker and the miller all look at this question of quality in wheat, from different viewpoints. He believes that the baking test is being used as a blanket quality test, which is more than can be expected of it. There are still many things to be learned about the baking

test. He gives a rather comprehensive discussion of the requirements set up by the wheat producer as to what a new wheat should be.

Call, Green and Swanson ( 2 ) direct attention to the fact that a good milling wheat must not only contain a high quantity of protein but also this protein must be of good quality. It is well known that there are differences in the quality of protein, considering the quantity as being constant. Amount of gluten and amount of protein are highly associated. Under Kansas conditions, deep red, hard, vitreous kernels, with a low test weight are usually high in protein.

Swanson ( 22 ) points out the complexities of colloidal behavior in dough. He especially emphasizes the important role of the particle as the unit of the starch and protein matrix, and its relationship to the environment. The forms of starch and protein particles, together with their most likely arrangement with regard to each other, are graphically illustrated.

Sharp and Gortner ( 19 ) found that viscosity in some flour suspensions varied with the rate of shear and that different flours vary in this respect. They observed that a flour-in-water suspension is very sensitive to mechanical

treatment, as repetition of the viscosity determination on a given sample for a number of times caused a marked decrease in its viscosity. Thus repetition has its influence on the accuracy of results. Little trouble was experienced in obtaining satisfactory accuracy in duplicate determinations with the MacMichael viscosimeter, although the results obtained were only comparative. Some flours with low baking strength yielded simple flour-in-water suspensions which gave relatively high viscosity readings.

Suspensions of flour in water are extremely labile systems and are affected by many factors which influence the viscosity of emulsoid colloids.

Snyder ( 21 ) in reporting some early experiments with the Foster gluten tester suggests that a flour which will produce a tall cylinder in the tester will usually produce a large loaf, although loaf size and gluten expansion are not always proportional. He also concludes that a high expansion of gluten is an indication of good bread making qualities.

## MATERIALS AND METHODS

### Parental Varieties

Clark, Martin and Ball ( 5 ) describe the Hard Federation parent as follows:

"plant - Spring habit, early, short, stem white, strong; spike awnless, oblong, dense, erect; glumes glabrous, brown, short, wide; shoulders wide, square; beaks narrow, acute, 0.5 mm long; apical awns wanting; kernels white, short, hard, ovate, with truncate tips; germ large; crease midwide, middeep, frequently pitted; cheeks angular to rounded; brush large, midlong.

History - Hard Federation was originated by selection from the Federation in Australia. The following history was recorded in 1914.

In consequence of the variations of the ordinary type exhibited by the strain of Federation wheat now being grown at Cowra Experiment Farm, it has been deemed advisable to apply a distinct name to it, and "Hard Federation" has been selected as the most appropriate. The departure from type was first noticed by J. T. Pridham, plant breeder, in 1907 or 1908, one of the plants selected from the stud plats being observed to thresh grain of remarkably hard and flinty appearance. The plant has the distinctive brown head and the general appearance of Federation in the field, but the grain was of a class that has never been seen in the variety before. The seed was propagated, and in 1910 the occurrence of the white heads was noticed, and from then until 1912 distinctly white heads were common among the brown, but in 1913 there were no white-eared plants, and it is hoped that the seed will now be true to type.

Hard Federation was first introduced into the United States in August, 1915, by the United States Department of Agriculture ( S. P. I. No. 41079). The seed was presented to the United States Department of Agriculture by George Valder, under-secretary and director of the Department of Agriculture, Sydney, New South Wales.

It was first grown at the Sherman County Branch Station, Moro, Oregon, in 1916. Experiments conducted by the department in Oregon and California from 1917 to 1919, reported by Clark, Stephens and Florell, have shown it to be a high yielding dry-land wheat, and it has since been

increased and distributed.

Distribution - Grown at several experiment stations in the western part of the United States and commercially to a slight extent in California and Oregon in 1920."

Clark, Stephens and Florell ( 3 ) state that of 130 lots of Australian wheat tested in nurseries on the Pacific coast, the Federation group, consisting of Federation, Hard Federation and White Federation appears best adapted. The results secured on the coast indicate that Hard Federation is higher yielding than the leading commercial varieties now grown and is well adapted to that region. Experiments indicate that Hard Federation is superior to leading commercial varieties in milling and bread making qualities.

Pridham ( 13 ) found that Hard Federation has a low migration ratio which means that the production of grain to straw is relatively high.

Pridham ( 14 ), in another paper, states that natural crossing is not uncommon in Hard Federation.

Richardson ( 16 ) states that Hard Federation is slightly earlier than Federation, has grain of better quality and in some districts yields as well as Federation.

The Kanred parent is described by Clark, Martin and Ball ( 5 ) as follows:

"Plant - Winter habit, midseason, midtall;

stem white, weak; spike awned, fusiform, middense, inclined; glumes glabrous, white, midlong, midwide; shoulders narrow, oblique to elevated, beaks 3 to 25 mm long; awns 3 to 10 cm. long; kernels dark red, midlong, hard, ovate to elliptical, germ small, crease narrow to midwide, middeep; cheeks rounded; brush small, midlong.

Kanred is very similar to Turkey, but is slightly more winterhardy and slightly earlier and can be distinguished from that variety by its resistance to some forms of both leaf and stem rust. This resistance to rust is an important factor in the ability of the variety to outyield Turkey wheat in many sections. It is about equal to Turkey in milling and bread-making value.

History - Kanred is the product of a single head selected in 1906 from the Crimean variety ( C. I. No. 1435 ), which had been introduced into the United States from Russia by the United States Department of Agriculture. The selection from which it descended was one of 554 head selections made in 1906 by Dr. H. F. Roberts, of the Botany Department of the Kansas Agricultural Experiment Station. In 1911 the more promising strains were included in experiments by the Agronomy Department of the Kansas Station, and several of them, including Kanred, were grown in field plots. In 1916 it was discovered to be rust resistant. During these years of preliminary testing of the Kanred wheat it was known by the number P - 762. In 1917 it was named Kanred, a contraction of Kansas Red. About 400 acres were seeded to this variety in the fall of 1917, more than 50,000 acres in the fall of 1918, and not less than 500,000 acres in the fall of 1919.

Distribution - Kanred was reported in 1919 from 23 counties in Kansas, 1 county in Michigan and 5 counties in Oklahoma. Probably 1,500,000 to 2,000,000 acres were sown to Kanred in the fall of 1920. It is grown also at experiment stations in most sections of the United States.

Synonyms - P-762, P-1066, and P-1068. P-762 was the designation under which Kanred wheat was known from the date of its selection, in 1906, until the time when it was named. P-1066 and P-1068 are two other pure-line selections developed at the Kansas Agricultural Experiment Station in much the same way as was Kanred. Both these strains have the rust resistance of Kanred and are identical in all morphological characters, but neither has been distributed for growing."

Salmon ( 17 ) published information concerning the establishment of Kanred wheat in Kansas. In addition to experimental data he quoted the opinions of thirty-four farmers scattered throughout the state, regarding the variety. Most of these opinions were favorable.

Clark and Salmon ( 4 ) gave a more detailed discussion of the value of Kanred in Kansas and other states.

The cross, Kanred x Hard Federation, was made at Chico, California in 1920 by V. H. Florell of the Office of Cereal Investigations, at the suggestion of Mr. J. A. Clark. The  $F_2$  generation was grown at Moro, Oregon in 1921-1922. In the fall of 1922 seed from 1,582 red-seeded  $F_2$  plants was planted in the crop improvement nursery at Manhattan, Kansas. After harvesting the  $F_3$  progenies all of the white seeded plants, with the exception of a few "testers" were discarded.

The number of selections of this cross grown in each subsequent generation in nursery rows and in field plots is shown in Table I. This table illustrates the rather

Table I. Sequential treatment of Kanred x Hard Federation selections, Agronomy nursery, Manhattan, Kansas, 1923 to 1929

Year	Generation	Kind of test	Number of strains
1922-23	F3	Plant rows	1580
1923-24	F4	Plant rows	763
1924-25	F5	Plant rows	605
		Single rod rows	82
1925-26	F6	Single rod rows	70
		Triplicate rod rows	129
		Replicate rod rows	7
1926-27	F7	Triplicate space - planted rows	19
		Triplicate rod rows	80
		Replicate rod rows	54
1927-28	F8	Plant rows	49
		Single rod rows	11
		Triplicate rod rows	23
		Replicate rod rows	31
		Advanced nursery	5
		Farm plots	3
1928-29	F9	Plant rows	66
		Single rod rows	69
		Triplicate rod rows	54
		Replicate rod rows	18
		Advanced nursery	3
		Farm plots	6
1929-30	F10	Plant rows	169
		Single rod rows	15
		Triplicate rod rows	34
		Replicate rod rows	18
		Advanced nursery	2
		Farm plots	1

rapid reduction in the number of lines grown. It also shows how the more promising strains have been advanced from individual plant rows to single row rows, replicated row rows and 1-40th acre field plots. The small number of strains now being grown in the nursery as compared to the large number in the earlier generations give some idea of the severity of the weeding out process. A few of the most promising strains were tested in 1-40th acre plots at the agronomy farm in 1928 and in 1929. Some of the more promising strains have also been included in preliminary trials at Columbus and Hays, Kansas and at a few cooperating stations in adjacent states.

The usual nursery methods have been used in the agronomic studies of the selections of this cross. Kanred was used as the check throughout the experiment. Hard Federation will not survive the winter at Manhattan and hence could not be included in the experiments. In all of the comparisons between the Kanred x Hard Federation selections and Kanred, data for the Kanred checks are taken from those plots which were grown in the same section of the nursery as the crosses.

The hybrid selections were first grown in plant rows where habit of growth, lodging, earliness, awn type, kernel

characters, etc., were observed. From the plant rows the more promising selections were advanced to the rod rows, either single or triplicated, depending on the merits of the strains and on the amount of seed and land available. The selections which proved their value in the single rod rows and triplicate rod rows were then tested in the replicated rod row series. The better selections were next tested in a special or advanced section of the nursery where each strain is grown in five to ten distributed three-row plots. Only about fifteen to twenty of the most promising new wheats on hand are ordinarily included in this section of the nursery, which also includes one or two standard varieties for comparison. Experience has shown that these nursery tests give a fairly reliable index of inherent yielding capacity.

The laboratories of the Milling Industry department were used in making the various quality tests. In nearly all of the laboratory tests conducted, the approved methods of the American Association of Cereal Chemists were used. Where modifications were made, mention of these is made in the text.

Detailed agronomic data were recorded in bound note books, which are on file in the Crop Improvement office of the Agronomy Department. Data on milling and baking

experiments and quality tests are filed in the Milling Industry Department.

## EXPERIMENTAL RESULTS

### Agronomic Characters

Earliness. It was pointed out in the introduction that earliness was one of the characters which it was desired to obtain in this cross. The spring wheat parent, Hard Federation, is early and it seemed quite probable that this character could be combined with the winterhardiness, yielding capacity and good quality of Kanred. Of the 1,504  $F_3$  lines grown in plant rows in the nursery in 1923, 310 were distinctly earlier than the check rows of the Kanred parent.

The earliness of the  $F_3$  Kanred x Hard Federation selections as compared with the Kanred checks is shown graphically in Fig. 1. The peak in the curve at May 26 gives clear evidence that there are types among the  $F_3$  selections that are distinctly earlier than the Kanred parent. The modal class for the selections is three days earlier than the modal class for the Kanred parent.

Further proof of the advantage which the selections have in earliness over the Kanred parent is seen in Fig. 2.

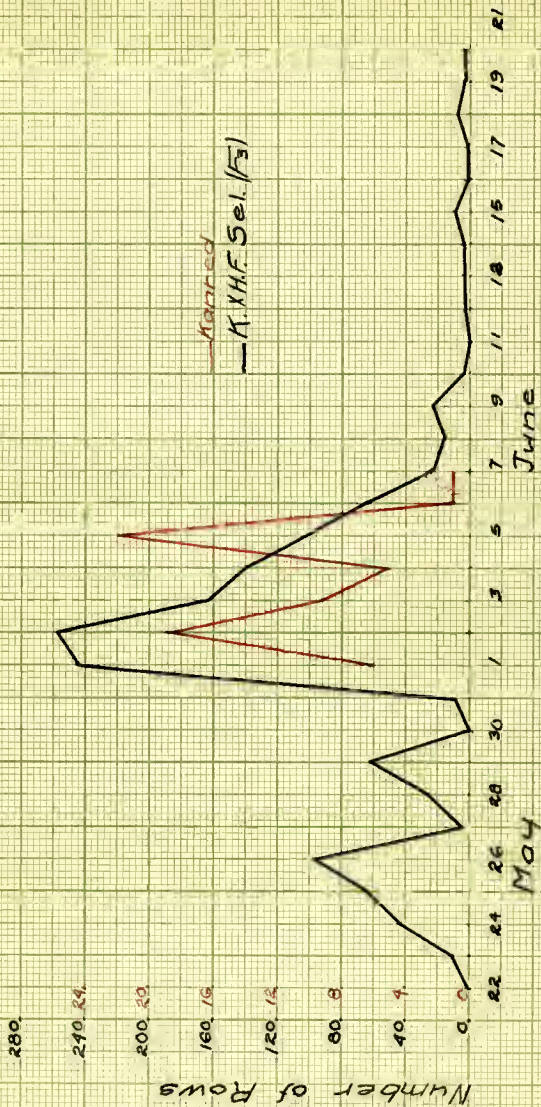


Fig. 1 Distribution of Dates Fully Headed, F3  
Kanred x Hard Federation, and Kanred,  
Agronomy Nursery, Manhattan, Kansas, 1923

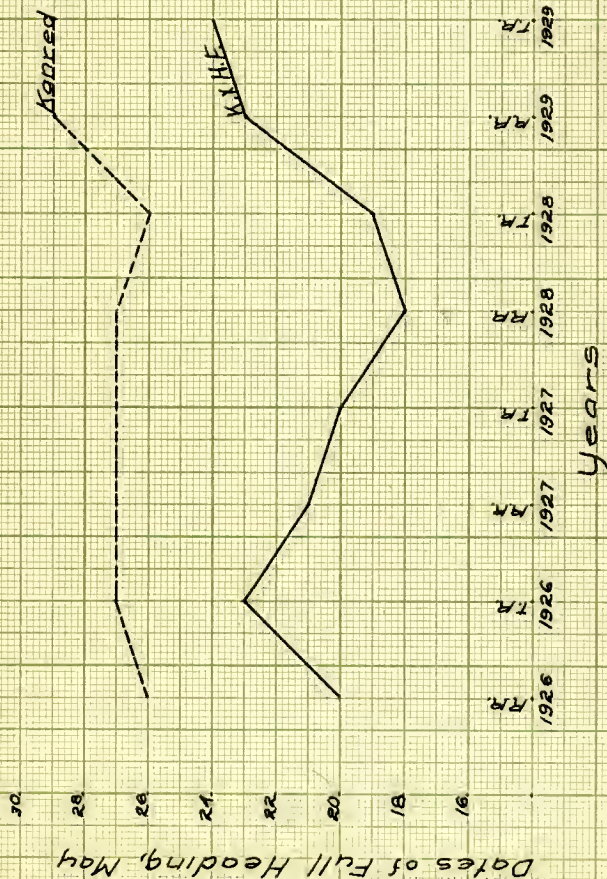


Fig. 2 Average Dates Fully Headed for Kanred  
x Hard Federation Selections and Kanred, Agronomy  
Nursery, Manhattan, Kansas, 1926 to 1929

The average heading dates of the hybrid selections for the four year period are all several days earlier than Kanred. These early types were favored in making selections for continuing the study of the cross. The spring types which segregated out and the less cold resistant winter types either winter killed or were discarded because of their evident lack of winterhardiness.

The average dates of full heading and ripening for the selections of Kanred x Hard Federation and adjacent Kanred checks grown in triplicated and replicated row rows in the nursery for the four year period 1926 to 1929 are given in Table II.

Table II. Average dates of full heading and ripening for Kanred x Hard Federation selections and Kanred checks, Agronomy nursery, Manhattan, Kansas, 1926 to 1929

Number of strains	Date full head (May)		Date ripe (June)	
	K. x H. F.	Kanred	K. x H. F.	Kanred
1926				
7	20	26	15	17
126	23	27	15	16
1927				
32	21	27	23	27
34	20	27	24	27
1928				
27	18	27	23	28
20	19	26	24	28
1929				
21	23	29	24	26
53	24	29	24	26
Averages	21	27	22	24

The dates in the first line for each year are for the strains grown in the replicated red rows and the dates in the second line are from the triplicated red rows.

The selections range from four to nine days earlier in heading and from one to five days earlier in ripening than the Kanred parent. As an average for the four years the hybrid selections are six days earlier in heading, and two days earlier in ripening, than Kanred. The crosses have a longer fruiting period than Kanred.

As previously mentioned, Hard Federation will not survive the Manhattan winters. For this reason no data on the earliness of the spring wheat parent are available.

While an early winter wheat is needed, a good standard variety such as Kanred cannot be discarded until a new variety is produced which is equal to, or better than, the standard, not only as regards earliness but in respect to other important characters.

The Kanred x Hard Federation selections are earlier than the Kanred parent. They are also earlier than Blackhull, which was grown as a check in the nursery in 1928 and 1929, and which is recognized as one of the earliest standard varieties of hard, red, winter wheat grown in Kansas.

The data on earliness from the field plots given in the following table do not show as much difference in heading

dates in favor of the Kanred x Hard Federation selections, and show that the strains tested in plots ripened only slightly earlier than Kanred.

Table III. Average dates of heading and ripening of Kanred x Hard Federation selections and Kanred grown in plots at the Agronomy farm, Manhattan, Kansas, 1928-1929.

Number of strains	Date full head (May)		Date ripe (June)	
	K. x H.F.	Kanred	K. x H.F.	Kanred
		1928		
3	19	23	24	25
		1929		
4	24	30	26	27
2	25	26	27	26
Averages	23	26	26	26

The data for 1928 are from single plots. The first line of data for 1929 is from single plots and the second line from triplicate plots.

The differences in the dates of full heading of the Kanred x Hard Federation selections are much more marked than in the dates ripe. This is due, in part at least, to the three days of hot drying winds which came at ripening time, causing all varieties to ripen very rapidly.

Referring to Table IV., it will be noticed that the date ripe for one of the Kanred x Hard Federation selections, Kans. # 2627, grown in triplicate plots in 1929 is unusually

Table IV . Agronomic data on Kanred x Hard Federation selections and Kanred checks, Agronomy Farm, Manhattan, Kansas, 1928 and 1929

=====							
Kansas number	Date full head MAY	Date ripe JUNE	Average lodging per cent	Breaking strength in lbs. per straw	Grain yield Bu. per A.	Plump-ness per cent	Test weight lbs.
-----							
<u>1-40th acre single plots, 1928</u>							
2625	19	23	0.0	.778	48.0	*	62.0
2626	20	26	0.0	.756	47.0		59.3
2627	19	24	0.0	.811	54.4		61.8
Averages	19	24	0.0	.782	49.8		61.0
Kanred	23	25	10.0	.670	44.8		60.3
<u>1-40th acre single plots, 1929</u>							
2650	21	24	1.3	.536	23.4	85	55.7
2648	23	25	23.3	.574	15.7	80	57.6
2651	24	25	22.0	.492	14.0	80	58.0
2649	28	27	36.3	.519	12.9	75	53.7
Averages	24	25	20.8	.530	16.5	80	56.3
Kanred	30	27	44.0	.488	13.7	50	51.1
<u>1-40th acre triplicated plots, 1929</u>							
2627	24	28	1.7	.624	26.4	82	58.0
2625	25	25	19.2	.572	17.3	83	57.3
Averages	25	27	10.5	.598	21.9	83	57.7
Kanred	26	26	9.3	.504	14.8	49	51.2
=====							

\* No notes taken, planted late, single plots. Not comparable.

late as compared with the other selections. The date of ripening of this strain was recorded as June 28 in all three plots. It may be that this strain is one of the later maturing types. However, two years testing may not furnish sufficient evidence for discarding this selection on the basis of date of ripening.

Since these hybrid selections have been under trial in plots at the Agronomy farm, Kansas #2,650 has been found to be segregating for earliness and height of plant. Re-selections have been made from this hybrid population which are being grown in the nursery in an attempt to isolate the types which are early and which seem to be well adapted to Kansas conditions.

The first bulking was done after the fourth hybrid generation; i. e., some of the more promising  $F_5$  lines were grown as bulk selections in single row rows. This may account for the segregation for earliness observed in the plots of Kansas #2,650. Most plant breeders now think that no bulking should be done until after the fifth and preferably the sixth generation. Experience has shown that in many cases segregation is still taking place even as late as the fifth or sixth generation. This is especially true where "size characters" such as earliness, height of plant,

winterhardiness, and other agronomic characters of economic importance are involved.

The data and observations on earliness show that some of the Kanred x Hard F<sub>2</sub> generation selections are earlier maturing than the Kanred parent. This is shown very clearly in Fig. 1 for the dates of full heading in the F<sub>3</sub> generation and is also very evident in subsequent generations, see Fig. 2.

Cold Resistance. One of the prime requisites of a winter wheat is that it be winterhardy enough to be safely grown in the region for which it is intended. The years which test the winterhardiness or cold resistance of wheat varieties are irregular in occurrence and in some regions come only at rare intervals. Thus at Manhattan, no reliable data on winterkilling of hard, red, winter wheats have been obtained since the winter of 1916-1917. For this reason artificial freezing trials have been resorted to as a means of measuring resistance to low temperatures. Freezing trials carried on in the greenhouse at Manhattan since 1926 have shown that varieties exposed to low temperatures in the refrigeration machine rank themselves in about the same

order as in field experiments carried on over a period of years.

In the  $F_3$  generation of this cross many of the selections were discarded because of their low degree of cold resistance. Some clear-cut differences in cold resistance are shown in Plates I and II. The photographs give evidence of a wide range of hardiness from non-hardy segregates to those as winterhardy as Kanred, the winter parent.

Data on the freezing injury of the hybrid selections, when tested for cold resistance by artificial freezing methods, are presented in Tables, V, VI and VII.

Table V. Freezing trials of Kanred x Hard Federation selections and Kanred, Agronomy greenhouse, Manhattan, Kansas, 1927-1928.

Kansas number	No. of tests	Average freezing injury, all tests	Relative injury, Kanred = 100%
253123*	28	72.7	90.6
2626	32	77.3	97.6
2625	29	71.8	97.8
2648	27	73.9	100.0
2649	26	84.3	105.8
254976*	10	97.4	99.7
243181*	9	96.3	100.1
255080*	6	96.5	100.5
2627	10	90.0	106.1
254990*	9	93.8	110.6
Kanred	95	72.7	100

\* Selection numbers.

Plate II. Winterhardiness of hybrid progenies, F<sub>3</sub>, Kanred x Hard Federation



Survival %  
1923 row no.

70  
6430

0  
6431

40  
6432

Plate I . Winterhardness of hybrid progenies, F<sub>3</sub>, Kanred x Hard Federation



Survival %  
1923 row no.

70 6367

5 6368

0 6369

70 6370

80 6371 27

21142

Table VI. Freezing trials of Kanred x Hard Federation selections and Kanred, Agronomy greenhouse, Manhattan, Kansas, 1928-1929.

Kansas number	Number of tests	Average increase over Kanred in freezing injury, per cent
2625	7	5
2651	9	6
2648	6	7
2650	10	10
2627	12	12
2649	8	13

Table VII. Freezing trials of Kanred x Hard Federation selections and Kanred, plants taken from variety plots and frozen in pots, Agronomy greenhouse, Manhattan, Kansas, March and April, 1929.

Kansas number	Average freezing injury			
	Early March	Late March	Early April	All tests
2627	83	80	72	78
2625	87	75		81
2648	87			87
2650	88			88
2649	92			92
Kanred	83	72	68	74

In all of these freezing trials, temperatures of from 6 to 14 degrees F for 12 hour periods were used. The temperatures used in the different experiments depended somewhat on the greenhouse temperatures to which the plants had been subjected previous to freezing. These averages represent large enough numbers of plants to be fairly

dependable.

Hard Federation, C. I. 4735, the spring parent, when subjected to artificial freezing proved to be very susceptible to cold injury. The data were secured under conditions which were different from those for Kanred and the hybrid selections, hence no direct comparisons are possible.

While there is not complete agreement as to the comparative cold resistance of Kanred and the hybrids in the different tests, it is evident that some of the hybrid selections which have been continued in the nursery and in plots at the farm are practically as cold resistant as Kanred. Most of these hybrid lines are probably not as hardy as Kanred. Only one of the segregates, Selection #253123, gave any evidence of having a significantly greater degree of cold resistance than Kanred.

Stiffness of Straw. The coming of the combine has accentuated the need of a stiff-strawed wheat. No easily recognized morphological differences have been found in the structure of the straw which are related to strength of straw. A method has recently been devised for measuring the differences of strength in straw. This method is the Salmon straw breaking machine which was devised by Professor S. C. Salmon in 1926 and perfected in 1927.

The machine measures the number of pounds required to break a given number of straws. The breaking strength as determined by this machine is correlated with field lodging notes, see Fig. 3.

The data on lodging of Kanred x Hard Federation and Kanred grown in the nursery are presented in the following table:

Table VIII. Lodging of Kanred x Hard Federation selections and of Kanred, Agronomy nursery, Manhattan, Kansas, 1926 to 1929.

Nursery	Number of strains	Per cent lodged	
		K. x H. P.	Kanred
1927			
Replicate	32	60	77
Triplicate	34	8	54
1928			
Replicate	27	22	49
Triplicate	20	18	28
1929			
Replicate	21	72	87
Triplicate	53	40	56
Averages		37	59

There was very little lodging in the dry season of 1926 and no lodging notes were taken.

There is a significant difference in the average lodging percentages of the Kanred x Hard Federation selections and

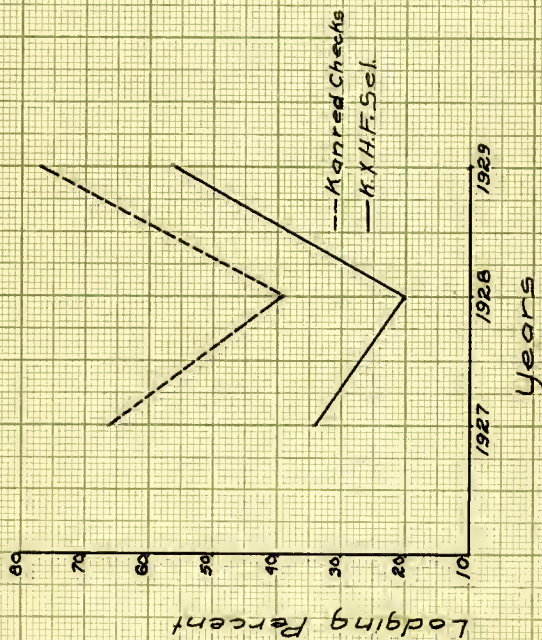


Fig. 3 Lodging, Kanred X Hard Federation Selections and Kanred Checks, Agronomy Nursery, Manhattan, Kansas, 1927 to 1929

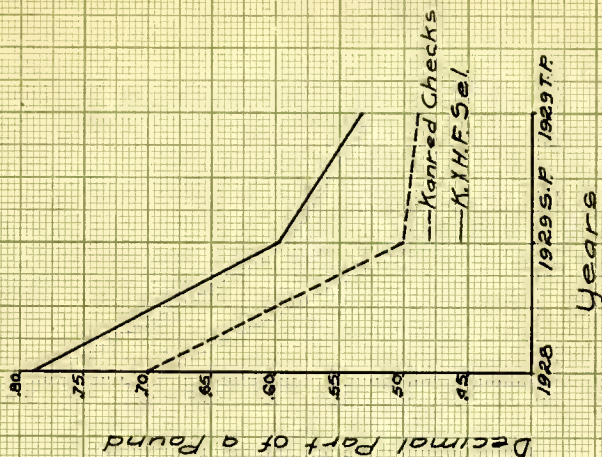


Fig. 3 Breaking Strength of Straw (Pounds Per Straw) Kanred X Hard Federation Selections and Kanred Checks Agronomy Nursery, Manhattan, Kansas, 1928 and 1929

the Kanred parent, which are 37 and 59, respectively. The differences in lodging are believed to be well beyond the limits of experimental error.

A special study of the stiffness of straw of Kanred and the Kanred x Hard Federation crosses was made in the lodging nursery in 1928 and 1929. Studies were made of the effects of applications of sodium nitrate and barnyard manure on yield, test weight, plumpness of kernels and protein content.

Sodium nitrate was applied at the rate of 150 pounds per acre. Nitrate applications were made on two different dates in the spring of each year, one in April and one in May. The manured plots received a liberal application of barnyard manure, early in the spring.

The lodging data secured from the lodging nursery are given in the following table:

		Lodging per cent		
		Nitrate	Unmanured	Manured
		1928		
K. x H.F.	12	*	*	12
Kanred		*	*	42
		1929		
K. x H.F.	8	42	20	67
Kanred		43	20	75

\* No notes taken.

There is a significant difference in the lodging of the Kanred x Hard Federation selections and the Kanred parent grown in manured ground in 1928. The data secured in 1929 are not very reliable as the whole nursery was almost completely lodged on two different occasions by severe wind and rain storms between heading and ripening. Before the storms came, the wheats in the nitrated plots were beginning to lean more than those in the unnitrated plots. This would be expected due to the slightly ranker growth of the plants in the nitrated plots. On the manured ground, the crosses lodged less than Kanred.

The data secured on lodging at the Agronomy farm are given in the following table:

Table X. Comparative lodging of Kanred x Hard Federation selections and Kanred, in plots at the Agronomy farm, Manhattan, Kansas, 1928-1929.

	Number of strains	Lodging per cent	
		K. x H. F.	Kanred
		1928	
Single plots	3	0	10
		1929	
Single plots	4	10	9.3
Triplicate plots	2	20.7	44.0
Averages		10.2	18.1

The tests in the farm plots show that the Kanred x Hard Federation selections were less lodged, on the average, than Kanred, as seen in Table X. The figures given in the table are averages of readings taken on several different dates, and in the case of the triplicate plots, of three plots of each strain. The lodging percentages given for the two strains grown in triplicate plots for 1929 should be fairly reliable because they represent an average of twelve readings for each strain, four different dates and three plots of each.

The differences in strength of straw of the crosses and Kanred are very apparent when measured with the Salmon apparatus. Some rather limited data on breaking strength are presented in Table XI and shown graphically in Fig. 3.

Table XI. Breaking strength of straw of Kanred x Hard Federation selections and Kanred grown at the Agronomy farm, Manhattan, Kansas, 1928-1929.

	Number of strains	Breaking strength in pounds K. x H.F. Selections	Kanred
		1928	
Single plots	3	.782	.670
		1929	
Single plots	4	.598	.504
Triplicate plots	2	.530	.488
Averages		.637	.554

The figures given for breaking strength of straw in Table XI., are on the basis of the pounds required to break a single straw. Ten trials with five straws to the trial give the average breaking strength in pounds. A study of the two tables, Tables X. and XI., shows a good agreement between the observations on lodging in the field and the number of pounds required to break a straw. Kanred lodged more than the Kanred x Hard Federation selections in the plots and required fewer pounds to break the straw.

The lodging notes taken in the Agronomy nursery and in the plots at the Agronomy farm, together with the data on the breaking strength of the straw, demonstrate quite clearly that the Kanred x Hard Federation selections are stronger strawed than Kanred.

Yield. The two characters, earliness and stiff straw, which constituted the major objective in making this cross, have been discussed in preceding paragraphs. Yield represents the combined effects of earliness, stiffness of straw, and other ancillary characters. Yield data from repeated rod row tests are available for four years, 1926 to 1929.

A comparison of the yields of Kanred x Hard Federation selections with the average of the Kanred parent grown in

adjacent checks is given in Table XII. The two yields marked (c) are very high, due in part at least, to the fact that they were grown adjacent to rows which were very low in yield; i. e., due to the effects of competition or interference.

The Kanred x Hard Federation selections have a striking advantage over the Kanred parent in yield. There are only a few cases, and these are all in the season of 1926, in which Kanred has outyielded any of the individual hybrid selections. In several of these instances the tests are not strictly comparable; i. e., the lower yielding hybrid was grown only in a single row or in triplicate rod rows while the yields reported for Kanred are from replicated rod rows.

The data in Table XII include all the yield data on the 21 hybrid selections grown in replicated rod rows in 1929 for the years as far back as these selections have been grown in repeated rod rows. Seven of these strains were tested only in single rod rows in 1926.

The three year average yields may be more significant than the four year averages because they are from more nearly comparable tests; i. e., no single row plantings were used after 1926.

All of the Kanred x Hard Federation selections yield

Table XIII. Yields of Kanred x Hard Federation selections,  
Agronomy Nursery, Manhattan, Kansas, 1926-1929

Selection number	Kansas number	1926	1927	1928	1929	Averages		
		Bushels per acre				4-yr.	3-yr.	2-yr.
254676	2650	34.4a	58.7b	61.8	38.9	48.5	53.1	50.4
254892	2649	30.5	71.1c	59.0	25.0	48.4	51.7	42.0
243181 A		41.1a	49.1	58.5	33.0	45.4	46.9	45.8
254524	2651	31.7b	53.4b	61.6	29.7	44.1	48.2	45.7
254624 A		32.5	55.4	54.6	33.0	43.9	47.7	43.8
254509	2648	33.6a	55.1	58.3	25.3	43.1	46.2	41.9
254990		40.8b	43.0	56.6	30.4	42.7	43.3	43.5
254981	2625	38.5b	37.6	58.5	31.7	41.6	42.6	45.1
243055		37.8	34.2	59.0	32.4	40.9	41.9	45.7
254634		36.2a	31.0b	62.6b	32.8	40.7	42.1	47.7
254898		30.2	31.3	68.1c	30.6	40.1	43.3	49.4
254581	2626	40.6a	37.1	57.4	22.7	39.5	39.1	40.1
255007		29.1b	44.5	57.1	26.9	39.4	42.8	42.0
254890		32.6b	28.1	60.5	22.9	38.0	37.2	41.7
255085		23.4a	29.4b	61.2	36.9	37.7	42.5	49.1
254976		21.4a	43.7b	60.0	24.3	37.4	42.7	42.2
254887 A		24.4	37.6	56.4	28.7	36.8	40.9	42.6
243518		30.7	26.7	56.7	22.7	34.2	35.4	39.7
243571		28.2	24.1	57.1	26.0	33.9	35.7	41.6
Averages		32.5	41.6	59.2	29.2	40.9	43.3	44.2
Kanred checks		36.9	14.7	53.7	16.2	30.4	28.2	35.0
Differences		4.4	26.9	5.5	13.0	10.5	15.1	9.2

A. Awnless selections.

a. Single rod row.

b. Three distributed single rod rows.

c. High yield probably due to low yield of adjacent row.

more than the Kanred parent on the basis of four, three and two year averages. In the upper half of the table all of the average yields of these crosses are above 40 bushels per acre.

The hybrid lines to which Kansas numbers have been assigned have been tested at the Agronomy farm for one or more years. Their position in the upper portion of the table is significant and indicates that some of the higher yielding lines were selected on the basis of preliminary nursery yield trials for testing in plots.

A summary of the yield data secured in the nursery tests is given in the following table:

Table XIII. Yields of Kanred x Hard Federation selections and Kanred, Agronomy nursery, Manhattan, Kansas, 1926 to 1929.

Year	Nursery	Number of strains	Bushels per acre		
			K. x H.F.	Kanred	Dif.
1926	Replicate	7	30.3	36.9	
	Triplicate	126	26.8	32.7	
	Averages		28.6	34.7	6.1
1927	Replicate	32	31.3	14.7	
	Triplicate	34	37.4	12.0	
	Averages		34.4	13.3	21.1
1928	Replicate	27	56.6	53.7	
	Triplicate	20	56.0	59.5	
	Averages		56.3	56.6	.3
1929	Replicate	21	14.9	16.2	
	Triplicate	53	27.0	23.5	
	Averages		21.0	19.8	1.2
AVERAGES			35.0	31.2	3.8

As an average of the triplicate and replicate rod rows for the four years, the crosses have an advantage of 3.8 bushels per acre over Kanred.

The Kanred x Hard Federation selections have a decided advantage over Kanred in 1927 and a slight advantage in 1929. In 1928 the crosses and Kanred made almost the same yields, while in 1926 Kanred outyielded the hybrid selections. The average yield of the crosses for the four year period is 35.0 and for Kanred 31.2 bushels.

Using another method of averaging the yields, namely averaging replicate rod row yields and triplicate rod row yields separately for the four year period, and comparing these averages, the Kanred x Hard Federation selections still have the advantage. The hybrid selections in replicate rod rows yielded 33.3 bushels and Kanred 30.4. In triplicate rod rows the crosses averaged 36.8, while Kanred averaged only 31.9 bushels.

A study of the average probable errors of the means may be of value in indicating the confidence which may be placed in the averages. These average probable errors are given in the following table:

Table XIV. Average probable errors of the mean yields, Kanred x Hard Federation selections and Kanred checks, Agronomy nursery, Manhattan, Kansas, 1926 to 1929.

Nursery	Number of strains	Average probable error of the mean	
		K. x H.F.	Kanred
		1926	
Replicate	7	1.71	3.00
Triplicate	126	2.17	2.57
		1927	
Replicate	32	2.17	2.52
Triplicate	34	2.58	1.06
		1928	
Replicate	27	1.63	0.99
Triplicate	20	1.67	3.28
		1929	
Replicate	21	1.56	0.74
Triplicate	53	2.13	1.30
Averages	Replicate	1.72	1.81
	Triplicate	2.14	2.05

In addition to the yields obtained in the regular nursery some interesting data were obtained in a special lodging nursery planted on low ground and treated with fertilizers.

The yields obtained in the lodging nursery are somewhat contrary to expectations due to the fact that the unmanured and unnitrated plots outyielded the manured and nitrated plots by substantial margins in both seasons. In contrast to the results obtained in the regular nursery the

Kanred checks outyielded the hybrid selections in all but one comparison.

Table XV. Yields of Kanred x Hard Federation and Kanred, lodging nursery, Manhattan, Kansas, 1928-1929.

		Yield in bushels per acre				
		No	No	No	No	
		Nitrate	nitrate	manure	Manure	Averages
		1928				
K. x H.F.*	12	58.3	77.2	49.5	48.9	58.5
Kanred*		85.8	116.0	57.9	53.4	78.3
		1929				
K. x H.F.	8	14.0	16.3	16.3	21.6	17.1
Kanred		15.3	21.1	21.1	17.6	18.8

\* The yields of the nitrated and no nitrate plots are from rows spaced two feet apart.

No explanation can be given for this reversal of order of yield of Kanred and the hybrid selections.

The yield data obtained from plots grown at the Agronomy farm, furnished through the courtesy of Professor S. C. Salmon, demonstrate significant differences in yielding ability between the Kanred x Hard Federation selections and the Kanred parent. These data are presented in Table XVI.

Table XVI. Yields of Kanred x Hard Federation selections and Kanred, Agronomy farm, Manhattan, Kansas, 1928-1929.

		Number of strains	Yield, bushels per acre	
			K. x H.F.	Kanred
			1928	
Single plots	3		40.8	44.8
			1929	
Single plots	4		16.5	13.7
Triplicate plots	2		21.9	14.8
Averages			29.5	24.1

The selections grown in plots have a significant advantage in average yield over the Kanred checks. This is in agreement with the data secured in the nursery. The five-bushel difference in favor of the hybrid selections, as an average for the two years, is certainly large enough to suggest that the earliness and stiff straw of those hybrid selections are contributing factors enabling them to yield more than the Kanred parent. Probably these crosses also have favorable combinations of growth factors or inherent factors for vigor and yield.

Since it is desirable to know something of the geographic range of adaptability of new wheat varieties some of the more promising hybrid lines have been tested in a preliminary way at a few cooperating stations. The data

from other stations are rather limited and are by no means conclusive but indicate something of the possible adaptation of these hybrid selections in regions differing from the Manhattan environment in which they were selected.

More of these hybrid selections have been tested in the winter wheat nursery at the Hays branch station and for a longer period of time than at any other station. The following data were furnished by Mr. A. F. Swanson, of the Hays station:

Table XVII. Yields of Kanred x Hard Federation selections and Kanred, in the nursery, Hays, Kansas, 1927 to 1929.

Year	Number of strains	Yield, bushels per acre	
		K. x H.F.	Kanred
1927	1	16.0	20.9
1928	17	41.9	43.7
1929	18	33.0	29.2
Averages		50.3	31.3

In addition to the yields reported from the rod rows, a single plot of selection #254580 (Kansas #2627) was grown in 1929. This selection yielded 26.7 bushels per acre as compared with 22.5 bushels for the adjacent Kanred check which was most nearly comparable.

These data from the Hays station suggest that Kanred may be better adapted to the Hays region than the particular

Kanred x Hard Federation selections which were tested there in 1927, 1928 and 1929. The hybrid selections yielded more than Kanred in 1929, both in the nursery and in the single plot. This can probably be accounted for by the fact that the Kanred x Hard Federation selections are earlier than Kanred and were past the critical part of the fruiting period before the coming of the hot winds. Mr. Swanson is of the opinion that had it not been for the hot winds coming just when they did, the Kanred would have outyielded the selections in 1929, as was the case in 1927 and 1928.

Some of the selections in the red-row nursery outyielded the Kanred parent both in 1928 and in 1929. While these preliminary yield trials and observations at Hays are not especially favorable for the crosses, it is probable that selections of Kanred x Hard Federation are on hand at Hays or Manhattan which will outyield Kanred in the Hays region, due primarily to their earliness and consequent ability to escape damage from hot winds and drought.

A few of the Kanred x Hard Federation selections were grown in the soft, red, winter wheat nursery at Columbus, in southeastern Kansas, in 1928 and 1929. Average yields of the crosses and of the Kanred parent grown as checks are given in the following table:

Table XVIII. Yields of Kanred x Hard Federation selections and Kanred, in the nursery, Columbus, Kansas, 1928-1929.

	Number of strains	Yield, bushels per acre	
		K. x H.F.	Kanred
		1928	
Triplicate	19	28.8	27.4*
		1929	
Triplicate	5	3.7	4.4
Replicate	4	7.6	4.4
Averages		13.4	12.1

\* Yield of Kanred from replicated rod rows in the same nursery.

No Kanred was planted in the triplicated rod row test in 1928, hence no direct comparison with the crosses is possible. They may, however, be compared with the average of two adjacent Fulcaster checks which yielded 27.7 bushels. Fulcaster is a standard bearded variety of soft, red, winter wheat grown in southeastern Kansas. The hybrid selections grown in replicated rod rows in 1929 yielded slightly more than Kanred. The low yields were due primarily to an abnormally late, wet spring.

The number of tests at Columbus has not been large enough to justify any definite conclusions as to the adaptation of these crosses in southeastern Kansas. This is especially true since most of the data were obtained in

1929 when abnormal weather conditions prevailed.

Two cooperating stations in adjacent states grew a few of the hybrid selections in rod row tests in 1929. Yields of the crosses and comparable Kanred checks are given in the following table:

Table XIX. Yields of Kanred x Hard Federation selections and Kanred at Stillwater, Oklahoma, and North Platte, Nebraska, 1929.

	Number of strains	Yield, bushels per acre	
		K. x H.F.	Kanred
North Platte, Nebraska	11	18.2	18.7
Stillwater, Oklahoma	10	7.2	9.2

The yields of the crosses are one-half bushel less than Kanred at North Platte and two bushels less at Stillwater.

Giving the results secured in the more extensive and longer continued tests in the nursery and in plots at Manhattan, the greater weight, which they deserve, it is clearly shown that the hybrid selections have given a greater yield, on the average, than the Kanred parent. The earliness and stiff straw of these hybrid lines are probably the major factors contributing to their higher yields. Under some conditions Kanred has outyielded the hybrid selections. This is to be expected.

Test Weight. Farmers, grain dealers and millers are agreed that high test weight in wheat is a very desirable character. Test weight is an important factor in determining the grade of wheat and is positively correlated with flour yield. In producing a new wheat, test weight is one of the characters which must be given consideration by the plant breeder.

The data on test weight which have been obtained from 1926 to 1929 in the nursery are presented in the following table:

Table XX. Test weights, Kanred x Hard Federation selections and Kanred checks, Agronomy nursery, Manhattan, Kansas, 1926 to 1929.

	Number of strains	Test weight, pounds	
		K. x H. F.	Kanred
1926			
Replicate rows	7	56.2	56.4
Triplicate rows	126	54.8	55.4
1927			
Replicate rows	32	56.7	*
Triplicate rows	31	56.5	50.8
1928			
Replicate rows	27	60.5	59.2
Triplicate rows	20	60.4	59.5
1929			
Replicate rows	21	54.0	51.9
Triplicate rows	31	55.5	51.9
Averages		56.8	55.0

\* Not enough grain for test.

The test weight in common with yield and many other characters varies with seasonal conditions. The Kanred x Hard Federation selections have a test weight 1.8 pounds heavier than Kanred, as an average of the four-year period.

The data on test weight of the crosses and of Kanred grown at the Agronomy farm are given in the following table:

Table XXI. Test weights, Kanred x Hard Federation selections and Kanred checks, grown in plots, Agronomy farm, Manhattan, Kansas, 1928-1929.

	Number of strains	Test weight, pounds	
		K. x H. F.	Kanred
		1928	
Single plots	3	61.0	60.3
		1929	
Single plots	4	56.3	51.1
Triplicate plots	2	57.7	51.2
Averages		58.3	54.2

The hybrid selections have higher test weights in every comparison, and have an average test weight 4.1 pounds heavier than Kanred.

Plumpness of Kernels. A comparison between the Kanred x Hard Federation selections and the Kanred parent as to plumpness of kernels has been made each year since the  $F_3$  generation. By selecting plump, hard, vitreous kernels it

was expected that it would be possible to isolate the best quality segregates from the hybrid population.

The data on kernel plumpness obtained in the nursery and on samples grown in plots at the Agronomy farm, indicate that measurable progress has been made by continued selection over a period of years, of the better individuals and lines within a heterozygous population.

The graphs of kernel plumpness for the  $F_3$ ,  $F_4$  and  $F_5$  generations of the cross, Figs. 4, 5 and 6, show clearly that progress has been made. In the  $F_3$  generation, Fig. 4, the Kanred checks produced plumper kernels than the hybrid selections. In  $F_4$ , Fig. 5, a marked improvement is noted for the crosses, which produced plumper kernels than the Kanred parent. The fifth generation, as shown in Fig. 6, shows a further improvement in kernel plumpness over the Kanred parent.

Further evidence of the efficacy of selection is provided by the smoothing out of the curve for kernel plumpness in the later generations. The curve for the  $F_3$  generation, Fig. 4, is plainly bi-modal. The curve for the  $F_4$  generation, Fig. 5, is less distinctly so, but still shows

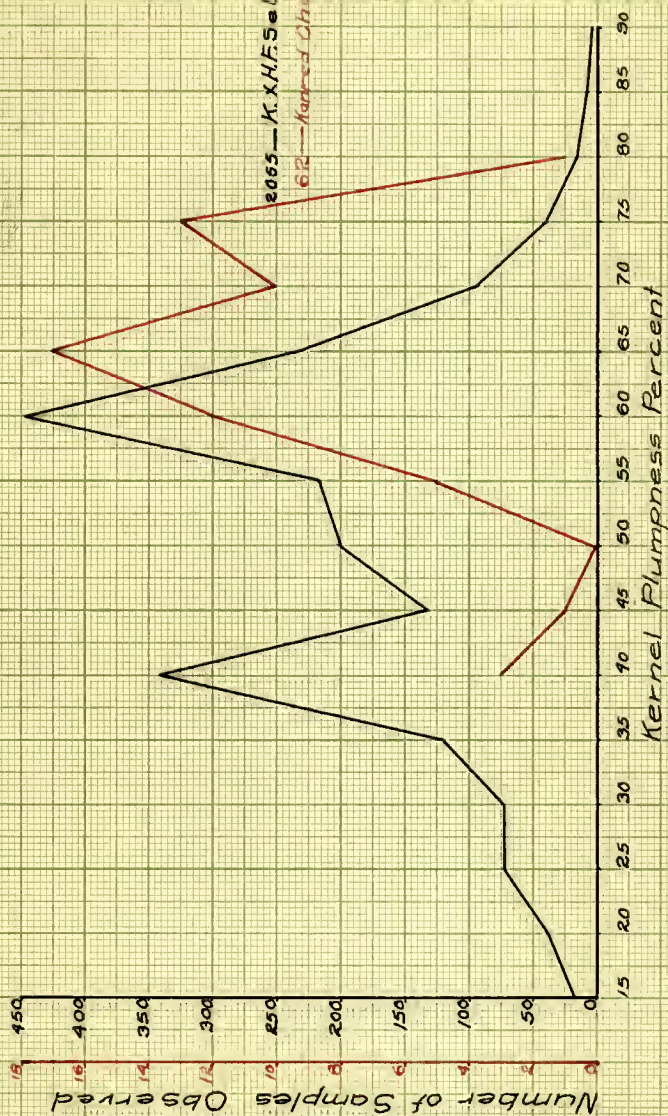


Fig. 4 Kernel Plumpness, Kanred (Bulk) and F3  
Generation of Kanred x Hard Federation (Plant)  
Selections, Agronomy Nursery, Manhattan, Kansas,  
1923.

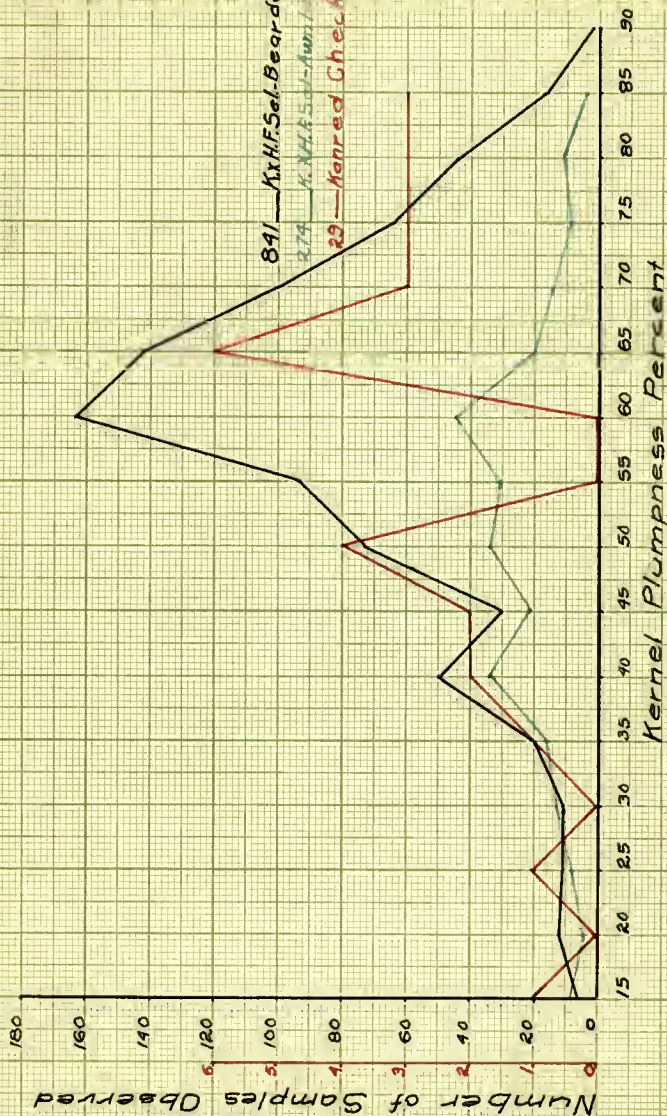


Fig. 5 Kernel Plumpness, Kanned (Bulk) and F<sub>4</sub> Generation of Kanned x Hard Federation (Plant) Selections, Agronomy Nursery, Manhattan, Kansas, 1924.

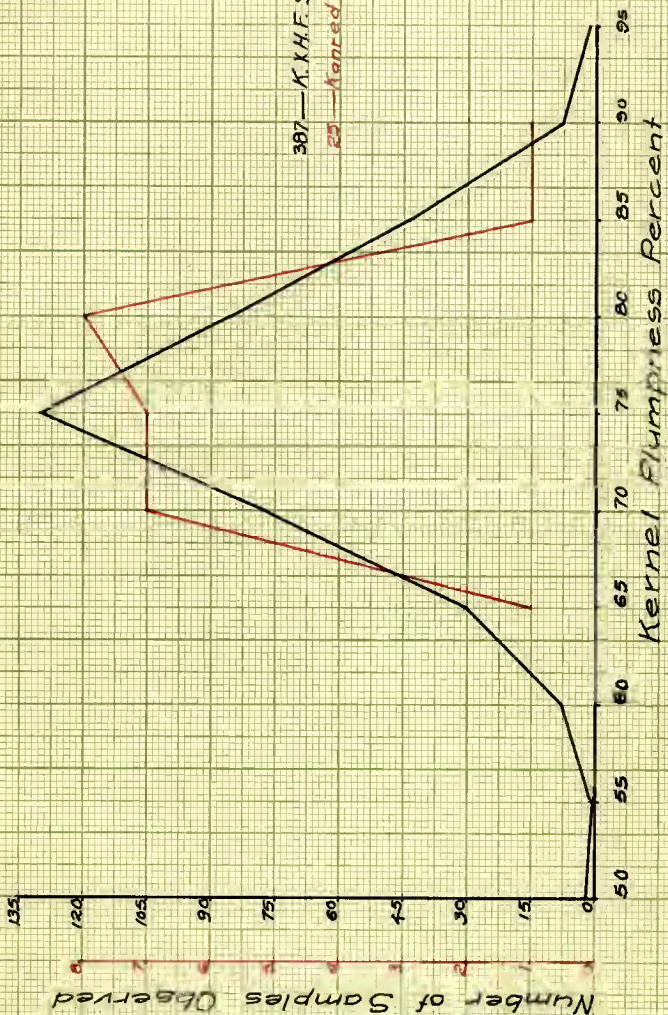


Fig. 6 Kernel Plumpness, Bulk Samples, Kanred and F<sub>5</sub> Generation of Kanred x Hard Federation Selections, Agronomy Nursery, Manhattan, Kansas, 1925

some tendency for bi-modality. The curve for the fifth generation approaches the normal curve and clearly indicates the progress that has been made by continued selection of the best lines.

In the fourth generation a comparison was made of the kernel plumpness of bearded and awnless segregates. This comparison is shown graphically in Fig. 5. The bearded selections produced slightly plumper kernels than the awnless selections, the average percentages being 56.1 and 55.5, respectively. In the third generation the average kernel plumpness for the bearded and awnless segregates was 53.9 and 47.6 per cent, respectively. These differences are not as great as have been observed in some varietal comparisons and in certain other crosses, but are in the same direction as in other comparisons of bearded and beardless segregates of other crosses tested at the Kansas station.

During the first five or six generations following the cross it would be expected that continued improvement could be made in kernel plumpness by selecting the plants and lines with the plumpest kernels. A study of Table XXII, giving the average kernel plumpness for the four years, 1926 to 1929, furnishes definite proof that such improvement has been made in handling this hybrid material. See Fig. 7.

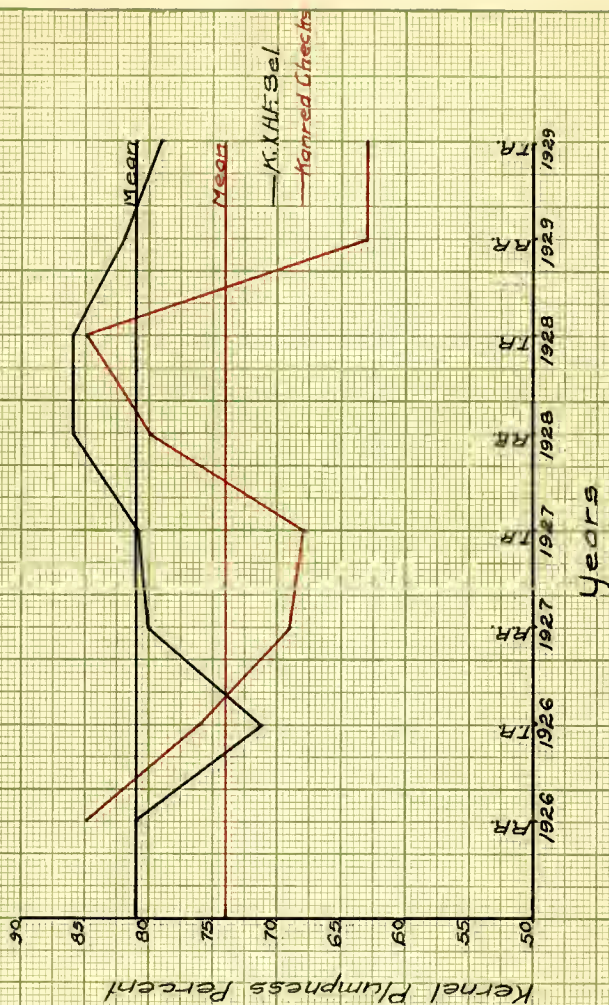


Fig. 7 Kernel Plumpness. Kanned X Hard Federation Selections and Kanned Checks, Rod Rows, Agronomy Nursery, Manhattan, Kansas, 1926 to 1929 Inclusive.

Table XXII. Kernel plumpness of Kanred x Hard Federation selections and Kanred checks grown in rod rows, Agronomy nursery, Manhattan, Kansas, 1926 to 1929.

	Number of strains	Kernel plumpness, per cent	
		K. x H.F.	Kanred
1926			
Replicate	7	81	85
Triplicate	126	71	76
1927			
Replicate	32	80	69
Triplicate	34	81	68
1928			
Replicate	27	86	80
Triplicate	20	86	85
1929			
Replicate	21	82	63
Triplicate	53	79	63
Averages		81	74

The average difference in plumpness between the crosses and the Kanred checks is seven per cent. This difference is believed to be significant.

Data on plumpness of kernels in samples from the plots grown at the Agronomy farm are given in the following table:

Table XXIII. Kernel plumpness, Kanred x Hard Federation selections and Kanred, Agronomy farm, Manhattan, Kansas, 1929.

	Number of strains	Kernel plumpness, per cent	
		K. x H.F.	Kanred
Single plots	4	80	50
Triplicated plots	2	83	49
Averages		82	50

These data show that the Kanred x Hard Federation selections have a significant and decided advantage in kernel plumpness over Kanred. At least part of this difference is probably due to the advantage the selections have in earliness. The selections were past the critical stage of their fruiting period when the three day period of hot winds came, while Kanred was not, and consequently suffered a loss in plumpness of kernels.

Some of the hybrid selections were planted at the Agronomy farm in 1928 but due to the fact that they were planted later than the other varieties they were considered not comparable and no plumpness notes were taken.

The differences between Kanred and the crosses in kernel plumpness so far discussed have been definite and clear cut. The plumpness notes taken in the special lodging

nursery, however, show only slight and not very consistent differences between Kanred and the hybrids.

The data secured on kernel plumpness in the special lodging nursery in 1928 and 1929 are presented in the following table:

Table XXIV. Kernel plumpness, Kanred x Hard Federation selections and Kanred, lodging nursery, Manhattan, Kansas, 1928-1929.

	Number of strains	Nitrated	No nitrate No manure	Manured	Averages
		1928			
K. x H. F.	12	85	88	88	87
Kanred		85	87	90	87
		1929			
K. x H. F.	8	76	79	69	75
Kanred		78	83	43	68

In 1929, some lodged and erect plants were harvested separately from the manured series. The lodged hybrids produced kernels which were 48 per cent plump, and Kanred 28 per cent. There was no difference between the kernel plumpness of the erect plants of the hybrid selections and of Kanred.

There is no significant difference between the hybrid selections and Kanred in 1928. In 1929 Kanred produced slightly plumper kernels except in the manured plots, where

the hybrids had a decided advantage.

Summary of Agronomic Characters. The Kanred x Hard Federation selections have been shown to be superior to Kanred in every character studied except cold resistance; i.e., in earliness, stiffness of straw, yield, plumpness of kernels and test weight. The yields of the crosses were relatively higher at Manhattan than at some of the cooperating stations where they were tested. Selections could probably be made from the hybrid lines on hand which would be well adapted to these other regions.

#### Quality Factors

Milling, baking and chemical determinations for some of the hybrid strains and the parents were made by the Department of Milling Industry. The data are offered in Tables XXV., XXVI., XXVII., XXVIII. and XXIX.

Flour Yield. Test weight and plumpness, two measures of kernel characters directly related to flour yield, have been discussed. It has been shown that the Kanred x Hard Federation selections are superior to Kanred in test weight and kernel plumpness.

The data presented in Table XXV. on the flour yield and

Table XXV. Milling and baking data on Kenred and Hard Federation, grown at Colby and Hays, Kansas, 1928-1929

Mill number	Source and variety	Wheat protein per cent	Flour yield per cent	Loaf volume c.c.	Color score	Texture score
Colby, 1928						
15109	Kenred	14.00	70.0	1730	96	88
15110	Hard Federation	14.00	67.0	1880	96	94
Colby, 1929						
15108	Kenred	16.15	67.3	1590	96	90
15107	Hard Federation	15.00	66.9	1780	96	94
Hays, 1929						
15111	Kenred	16.35	67.8	1800	96	90
15112	Hard Federation	17.30	63.0	1870	96	94

Table XXVI. Milling and baking data, Kanred x Hard Federation selections and Kanred checks, Agronomy nursery, Manhattan, Kansas, 1928

Mill number	Kansas number	Yield bushels per acre	Wheat protein per cent	Test weight pounds	Flour yield per cent	Loaf volume c. c.	Color score	Texture score
12892	243055	59.0	13.35	61.3	66.7	1650	95	97
12893	255007	57.1	13.60	61.7	66.2	2160	99	98
12894	254976	60.0	13.45	60.2	66.7	2135	99	98
12895	243518	56.7	13.50	61.0	67.3	2190	99	98
12896	243571	57.1	14.00	60.7	67.3	1940	99	98
12897	254890	60.5	13.25	60.0	66.7	2000	99	98
12898	254990	56.6	14.20	61.2	66.7	2050	98	96
12899	255085	61.2	14.40	60.8	66.0	1970	98	96
12900	254887	56.4	13.65	59.3	66.0	2115	99	98
12901	243181	58.5	12.40	59.7	66.3	2025	97	95
12902	254624	54.6		60.3	67.3	1735	97	95
12903	2650	61.8	14.30	60.1	66.7	1960	99	98
12904	2626	57.4	14.60	60.5	66.7	2010	98	96
12905	2649	59.0	13.80	58.9	66.7	1800	97	93
12906	2648	58.4	13.90	61.0	68.7	2030	97	97
12907	2625	58.5	14.00	61.2	68.0	1845	97	91
12908	253123	57.7	13.85	60.5	67.8	1875	98	91
Averages		58.3	13.77	60.5	66.9	1970	98	96
Kanred		52.48	15.54	58.5	67.2	2120	99	98

Table XXVII. Milling and baking data, Kanred x Hard Federation selections and Kanred checks, single plots, Agronomy Farm, Manhattan, Kansas, 1928

Mill number	Kansas number	Yield bushels per A.	Wheat protein per cent	Test weight lbs.	Flour yield per cent	Loaf volume c.c.	Color score	Texture score
12617	2627	54.4	13.60	62.0	63.3	1875	99	94
12622	2625	48.0	12.10	61.4	70.0	1855	98	88
12623	2626	47.0	12.90	60.4	69.5	1940	99	94
Averages		49.8	12.87	61.3	67.6	1890	99	92
12594	Kanred checks	46.4	12.50	61.5	70.0	2035	99	97

Table XXVIII. Milling and baking data, Kanned x Hard Federation selections and Kanned checks, Agronomy nursery, Manhattan, Kansas, 1929

Mill serial number	Kansas number	Yield bushels per acre	Wheat protein per cent	Test weight pounds	Flour yield per cent	Loaf volume c. c.	Color score	Texture score
15078	2648	25.3	14.35	54.0	65.8	1920	96	95
79	2625	31.7	14.85	55.0	70.0	1700	96	88
80	2650	38.9	13.80	55.2	70.0	1890	96	88
81	243055	32.4	15.15	54.3	65.0	1900	96	95
82	255007	26.9	15.25	53.1	65.6	1870	96	90
83	254524	29.7	13.60	54.2	64.7	1880	96	92
84	254976	24.3	13.10	52.1	66.8	1850	96	92
85	243518	22.7	13.20	55.1	67.7	1840	96	88
86	254892	25.0	15.45	51.3	64.7	1900	94	96
87		23.8	15.10	53.7	65.0	1950	94	96
88	243571	26.0	14.70	53.4	65.3	1770	94	95
89	254890	22.9	14.95	50.3	62.7	1790	94	91
90	254990	30.4	16.15	54.3	57.9	1825	96	92
91	255085	36.9	15.25	55.8	74.7	1740	92	86
92	254898	30.6	14.95	55.1	67.1	1815	96	92
93	254887	28.7	15.85	52.2	65.8	2035	97	96
94	243181	33.0	15.10	54.3	67.1	1780	96	91
95	254624	33.0	14.85	55.1	67.6	1935	96	92
96	285192	35.1	15.80	55.7	65.5	1510	98	90

(Continued on next page)

(Table XXVII continued)

Mill serial number	Kansas number	Yield bushels per acre	Wheat protein per cent	Test weight pounds	Flour yield per cent	Loaf volume c. c.	Color score	Texture score
97	285536	38.0	14.55	54.9	67.1	2020	97	96
98	286222	26.0	16.00	55.9	63.8	1705	98	90
99	286352	33.0	13.60	55.9	66.9	1960	97	96
15100	286276	28.2	15.00	53.1	66.4	1655	95	88
1	286277	32.4	15.80	55.7	69.4	1545	92	90
2	254580	28.7	15.45	55.5	66.7	1535	99	90
3	254580	27.6	15.40	55.2	67.0	1910	97	94
4	254580	34.1	15.55	54.1	63.3	1700	95	88
5	254580	28.5	15.85	57.3	68.3	1575	99	90
Averages		29.8	14.96	54.4	66.6	1800	96	92
Kanred		22.4	17.35	51.9	62.0	1955	96	92

Table XXIX. Milling and baking data, Kanred x Hard Federation selections and Kanred checks, Agronomy Farm, Manhattan, Kansas, 1929

Kansas number	Yield bushels per A.	Wheat protein per cent	Test weight lbs.	Flour yield per cent	Loaf volume c.c.	Color score	Texture score
2627	26.4	15.05	58.9	70.0	1970	96	98
2625	17.3	14.60	58.9	70.5	1860	96	96
Averages	21.9	14.83	58.9	70.3	1915	96	97
Kanred checks	14.8	18.30	51.8	66.0	2060	96	98

other quality factors of the parents show that the samples of Kanred grown at Hays and Colby in 1928 and 1929 produced higher flour yields but lower loaf volumes and texture scores than Hard Federation. The data are limited and possibly not very significant because of the fact that Hard Federation is a hard, white, spring wheat grown under conditions to which it is not very well adapted, while Kanred is a hard, red, winter wheat grown in a region to which it is very well adapted and for which it was bred.

The data on flour yield of samples milled from the nursery and farm plots in 1928 and 1929 are summarized in the following table:

Table XXX. Flour yield, Kanred x Hard Federation selections and Kanred, nursery and farm plots, Manhattan, Kansas, 1928-1929.

	Number of strains	Flour yield, per cent	
		K. x H. F.	Kanrod
1928			
Nursery	17	66.9	67.2
Farm plots	3	69.6	70.0
1929			
Nursery	29	66.6	62.0
Farm plots	2	70.3	66.0
Averages		68.4	66.3

The hybrid selections have a two per cent advantage over Kanred in average flour yield, which probably is

significant. These results are in complete agreement with the data on test weight and plumpness given in Tables XX., XXI., XXII., and XXIII. The selections excel Kanred in these characters and would therefore be expected to have a higher flour yield than Kanred.

More detailed data on flour yield and other quality factors of Kanred and the crosses are presented in Tables XXVI., XXVII., XXVIII. and XXIX.

Protein Content. The protein test is now regarded by many investigators and members of the grain and milling trades as the best rapid, available method for determining quantitatively the baking quality of wheat. The protein test affords an acceptable yardstick for the measurement of quantity of gluten but does not indicate the quality of the gluten.

Limited protein data on the parents are given in Table XXV. Kanred is high in one comparison, Hard Federation is high in one, and they are the same in the third.

Protein determinations have been made on the Kanred x Hard Federation crosses only since 1927. These data are summarized in Table XXXI.

Table XXXI. Protein percentages, Kanred x Hard Federation selections and Kanred, Agronomy nursery, Manhattan, Kansas, 1927 to 1929.

	Number of strains	Protein percentages	
		K. x H.F.	Kanred
1927			
Replicate rows	27	14.0	15.5
Triplicate rows	27	13.9	15.8
1928			
Replicate rows	18	13.5	15.3
Triplicate rows	9	13.5	14.0
1929			
Replicate rows	21	14.9	16.2
Triplicate rows	33	14.9	14.6
Averages		14.1	15.2

There is a significant difference in the protein content of Kanred and the crosses, the latter being about one per cent lower in protein content than Kanred. Since plumpness of kernels or test weight and protein content are known to be negatively correlated, this difference would be expected, since the selections have an advantage over Kanred in plumpness of kernels.

Sewell and Swanson, (18), found that where the nitrate content of the soil is increased by tillage methods,

the protein content of the wheat will be correspondingly increased.

Gericke, ( 10 ), considers that varietal individuality is an important factor in the efficient use of fertilizers. He found that increasing the nitrates in the soil increased the protein content of the wheat but that there are some exceptions due to varietal individuality.

The observations made in the lodging nursery are in agreement with work cited, as can be seen in Tables XXXII, XXXIII and XXXIV.

Table XXXII. Protein percentages of Kanrod x Hard Federation selections and Kenred; lodging nursery, Manhattan, Kansas, 1928.

Selection Number	Nitrated plot	No nitrate	Manured plot	No manure	
254892	13.80	13.15	13.40	13.00	
254529	13.10	12.95	13.50	14.20	
254676	14.90	14.40	14.40	13.90	
255108	15.20	14.15	14.40	13.10	
245181	15.05	13.40	13.85	13.05	
254624	15.65	14.05	12.90	12.90	
Averages	14.62	13.68	13.74	13.36	AVERAGES 13.85
Kenred	14.05	13.25	15.50	13.90	14.17

Table XXXIII. Protein percentages of Kanred x Hard Federation selections and Kanred, lodging nursery, Manhattan, Kansas, 1929.

Selection number	Nitrated plot	No nitrate no manure	Manured plot
254524	12.75	12.78	16.68
254676	13.70	13.20	15.11
243181	14.78	14.38	16.28
254624	14.03	13.30	15.75
254892	13.03	12.83	16.65
254529	12.80	12.53	15.26
254981	14.38	14.13	16.35
254628	13.93	13.33	15.22
Averages	13.68	13.31	15.91
Kanred	14.20	13.00	18.19

Table XXXIV. Protein percentages of Kanred x Hard Federation selections and Kanred, lodged and erect plants, lodging nursery, Manhattan, Kansas, 1929.

Selection number	Manured ground	
	Erect plants	Lodged plants
254524	14.78	18.58
254676	15.18	15.05
243181	16.38	16.18
254624	15.93	15.58
254892	14.95	18.35
254529	14.03	16.50
254981	16.05	16.65
254628	15.15	15.30
Averages	15.31	16.52
Kanred	16.43	19.95

The wheats grown on the nitrated plots had a higher percentage of protein than those grown on the untreated plots. The protein studies made in the lodging nursery agree with those made in the regular nursery and show that Kenred has a higher average protein content than the hybrid selections. This difference between Kenred and the crosses is in agreement with the conclusion of Gericke (10) as to the existence of varietal response to varying fertility and other environmental factors.

The protein content of the individual hybrid selections varies considerably even within one season as shown in Tables XXXII and XXXIII. Thus, in 1928 on the untreated plots, they varied from 12.9 to 14.4 per cent and in 1929, from 12.5 to 14.4 per cent.

In 1929 a study was made of the protein content of the grain of lodged and erect plants on the manured ground, Table XXXIV. These samples were taken at harvest time by securing enough lodged and erect plants to get a sample of each strain for protein determination in each of the two manured series.

As would be expected from the well known fact that lodged wheat produces shrunken grain and that such shrivelled grain is usually high in protein, the samples

from lodged plants had a higher average protein content than the samples from the erect plants.

There is less difference in protein content of lodged and erect plants of the hybrid selections than of Kanred. This is to be expected, since the hybrid selections were less seriously lodged than Kanred.

Applications of nitrogen, whether in the form of sodium nitrate or barnyard manure, have significantly increased the protein content of the selections and of Kanred in both years. Manure produced a small increase in the average protein content of the crosses in 1928 and a much larger increase in 1929. This greater difference in 1929 may be attributed to the serious lodging of the plants on the manured plots which took place at an unusually early date. The protein percentages of wheat grown on the manured plots in 1929 were not secured on bulk samples. They are averages of the samples from lodged and erect plants and may not accurately represent the true average for the whole row because all rows were not lodged to the same extent.

Loaf Volume, Texture and Color. Commercial bakers desire flours, by the use of which, loaf volume and number of loaves obtained per barrel of flour may be increased

at a minimum expenditure. Wheat breeding operations should be planned and carried on with these criteria in mind.

The baking results have been obtained by the use of the so-called "K.S.A.C. high speed mixer". The dough is given severe mechanical treatment for a five minute period. It is then placed in the baking pan, allowed to rise to a given height and baked.

Comparison of the loaf volumes of the parents are given in Table XXV. Hard Federation has a higher average loaf volume than Kanred. These data are limited. However, they indicate that, at least under certain environmental conditions, Hard Federation is superior to Kanred in loaf volume.

Hard Federation, as grown at Hays and Colby, is also superior to Kanred in texture as shown in Table XXV. The color scores of the two varieties are the same.

Data on loaf volume of the hybrid selections and of Kanred grown in the nursery and in plots at the farm are presented in Tables XXVI., XXVII., XXVIII. and XXIX. and are summarized in Table XXXV.

Some of the differences are illustrated in plates III., IV., V. and VI.

Plate III. Kanred x Hard Federation selections, Agronomy farm, 1929

Baking test



Wheat protein %  
Loaf volume c. c.  
Color score  
Texture score  
Kansas No.

14.6	15.5
1640	2005
97	97
90	98
2625	2627

CJ+15

Plate IV. Kanred x Hard Federation selections and Kanred, Agronomy nursery, 1929

Baking test



Name	Kanred	Kan. #2648	Sel. #255007	Kan. #2625
1929 row no.	Bulk of nursery cks.	941	188	944
Mill no.	15053	15078	15082	15079
Yield - bu.	22.4 (T.R.)	25.3	26.9	31.7
Test weight lbs.	47.8	54.0	53.1	55.0
Protein %	14.64	14.35	15.25	14.86
Loaf vol. c. c.	1830	1920	1870	1700
Texture score	90	95	90	88
Color score	96	96	96	96

Plate V. Kanred x Hard Federation selections, Agronomy nursery, 1929  
Baking test



Selection no.	254580-(R.N)	254580-(R.N.)	236276
Mill serial no.	15103	15105	15100
Protein per cent	15.40	15.85	15.00
Yield - bu. per A.	27.6	28.5	28.2
Test weight, lbs.	55.6	57.3	53.1
Flour yield, per cent	68.3	67.5	66.4
Loaf volume, c. c.	1910	1575	1655
Texture score per cent	94	90	88
Color score per cent	97	99	95

Plate vi. Baking test  
 Kanred x Hard Federation selections, Agronomy nursery, 1929



Selection no.	254387
Mill serial no.	15093
Yield - bu. per A.	28.7
Protein per cent	15.85
Test weight lbs.	52.2
Plumpness per cent	80
Leaf volume, c. o.	2035
Flour yield, %	65.8
Texture score %	96
Color score %	97

286222
15098
26.0
16.00
-----
85
1705
63.8
90
98

285192
15096
35.1
15.80
55.7
84
1510
65.5
90
98

Table XXXV. Loaf volume, Kanred x Hard Federation selections and Kanred, Agronomy nursery and farm, Manhattan, Kansas, 1928-1929.

Test	Number of strains	Loaf volume, c. c.	
		K. x H.F.	Kanred
		1928	
Nursery	17	1970	2120
Farm	3	1890	2035
		1929	
Nursery	29	1800	1955
Farm	2	1915	2060
Averages		1894	2043

The average loaf volume of the crosses is significantly less than that of the Kanred parent, the latter having an advantage of about 150 c. c. over the average of the hybrid lines. Kanred is a variety which has excellent milling and baking qualities and it is a difficult task to produce a new variety superior to it.

The loaf volumes given in Table XXXV are averages. A study of the data in Tables XXVI and XXVIII shows that there are a few individual selections which are superior to Kanred in baking quality and a larger number which are about equal to Kanred in loaf volume. The crosses which baking tests have shown to be decidedly inferior to Kanred have been, or will be, discarded.

The segregation which has occurred is most clearly shown in Plate IV. Loaf number 2 is superior to loaf number 1, the Kanred parent, and is superior to the other two hybrid selections. Loaf number 3 is intermediate in quality and is similar to Kanred. Loaf number 4 is the poorest of the hybrid lines baked in this group and is decidedly inferior to Kanred.

The loaves pictured in Plates III, V and VI also show very clearly, segregation for factors affecting baking quality. The differences are beyond the limits of experimental error and are significant.

Differences in texture as well as differences in volume of three of the crosses are very clearly shown in Plate V. Loaf number 6 exhibits a very fine, close texture. Selections which produced loaves like this usually had grain which appeared to be of good quality. On the other hand, loaves of the coarse texture found in loaf number 1, were usually baked from samples which had grain of poor or mediocre quality.

The exact cause of the fine, dense texture found in loaf number 6, Plate V, is not known. Loaves having this fine, close texture are sometimes produced by standard varieties of hard red winter wheat of very high protein content.

Gluten Quality. An attempt was made to differentiate certain standard varieties, such as Blackhull and Kanred, and also individual strains of Kanred x Hard Federation by gluten washing. The method used was that suggested by Dill and Alsberg (9); viz., to make up a dough using 25 grams of flour, soaking for an hour and then washing out the starch with a solution of 20 c.c. of four per cent di-sodium phosphate and 100 c.c. of four per cent mono-sodium phosphate. The data obtained are not quantitative. They are merely descriptive notes on the stretch, elasticity and fineness of texture of the gluten.

Seventeen samples of Kanred x Hard Federation, in addition to Kanred and Blackhull, were included in these studies. The conclusions reached on the quality of these samples were not in close agreement with the results of experimental baking tests of the same strains, in which the high speed dough mixer was used.

These seventeen samples included four lines which produced loaves of poor quality, and it was hoped the determinations might enable one to identify these four samples. Such, however, was not the case. In some cases, these samples having poor baking quality, were described as having very elastic, very pliable, or very good gluten.

These tests are not extensive enough to justify the conclusion that gluten washing is not a useful index of gluten quality. They do indicate that an operator with only limited experience cannot expect to detect the finer and less obvious differences in actual baking qualities of varieties and crosses.

Viscosity. A few years ago many cereal chemists in mill laboratories were using the viscosimeter in an attempt to distinguish between strong and weak flours. They have not been entirely successful in this attempt and at present less emphasis is placed on viscosity determinations.

Viscosity determinations were made on sixteen of the Kanred x Hard Federation selections grown in the winter wheat nursery in 1928.

Twenty grams of flour were soaked in 100 c.c. of distilled water for approximately an hour. The MacMichael viscosimeter with a two centimeter plunger, a small cup and number 30 certified wire was used. Readings were first taken on the neutral solution and then on the acid solution of the same sample. Three-tenths c.c. of 80 per cent lactic acid was used for the acid reading.

The data, including protein content, are presented in

Table XXXVI. They show that duplicate readings on the viscosimeter do not always check very closely, and that there is no close relation between average viscosity readings and either protein content or loaf volume. The averages of viscosity readings, protein percentages and loaf volumes for the first eight samples (high viscosity) and for the last eight samples (low viscosity) listed in Table XXXVI are as follows:

Table XXXVII. Average viscosity, protein percentages, and loaf volumes of sixteen Kanred x Hard Federation selections.

	Viscosity	Protein per cent	Loaf volume
Higher viscosity	247	13.96	1954
Lower viscosity	202	13.57	2016

The average viscosity readings show some relation to protein percentages, but are not in the same order as loaf volumes.

At the fifteenth annual convention of cereal chemists held at Kansas City, Missouri, in May, 1929, it was generally agreed by the chemists that the viscosity test was limited in its adaptations. It was stated that one of the uses to which it might be applied was testing differences in gluten strength between crops from different years, where

Table XXXVI. MacMichael Viscosimeter readings, Kanred x Hard Federation selections and parents.

Mill number	Protein per cent	Loaf volume c. c.	Degrees MacMichael first sample		Degrees MacMichael duplicate sample		Average degrees	
			neutral	acid	neutral	acid	neutral	acid
12904	14.60	2010	27	253	31	275	29	264
12906	13.90	2030	25	252	25	265	25	259
12908	14.20	2050	25	270	22	245	24	258
12903	14.30	1960	24	267	26	240	25	254
12892	13.35	1650	25	250	25	256	25	253
12905	13.80	1800	21	243	22	235	22	239
12895	13.60	2190	30	213	24	240	27	227
12896	14.00	1940	27	230	27	220	27	225
12897	13.25	2000	25	225	30	221	28	223
12900	13.65	2115	21	166	49	275	35	221
12899	14.40	1970	40	215	40	225	40	229
12894	13.45	2135	25	198	25	230	25	214
12893	13.60	2160	18	212	24	205	21	209
12901	12.40	2025	25	175	26	200	26	188
12908	13.85	1875	26	181	24	178	25	180
12876(a)	15.54	2120	6	179	17	169	12	174
12907	14.00	1845	21	165	21	152	21	159
11522(b)	12.30	1765	22	90	20	100	21	95

(a) Kanred

(b) Hard Federation

the differences are often wide. Another possible application was in detecting differences in carlot shipments of wheat to a mill, or flour to a bakery. Minor differences due to temper, milling, bleaching or even rather wide varietal differences are not always clearly revealed by the viscosimeter.

The following letter by Mr. J. T. Pearson, formerly of the Southwestern Milling Company, Kansas City, Missouri, gives the views of the chemists in a Kansas City mill laboratory with regard to the limitations of the viscosimeter;

"It is true that I have done considerable work with the viscosimeter and Doctor Sasse and I have come to the same rather definite conclusions regarding it. We first gathered information from every possible source. I spent some time in Mr. Dunham's laboratory here in Kansas City and had a somewhat lengthy correspondence with Doctor Bailey and many others. After much experimenting, we decided upon a method entirely our own. We took what we believed to be the best of all of the methods that we knew about and added a few of our own ideas and finally developed a system that we believe superior to any other method that we know about for our purpose.

We found all investigators using a definite amount of flour. Some used twenty grams for each test and some used twenty-two grams, but they never varied the amount of flour used in a test. We found that a high protein flour will always give a higher viscosity reading than a low protein flour when the same amount of flour is used in each case. We were not interested in the amount of protein shown by the viscosity test but wanted some indication of the quality of the gluten, therefore, we scaled the amount of flour according to the amount of protein that it carried. We took as a standard 20 grams of flour for a 10% protein. Less flour is used for more protein and more flour for less

protein, always in proportion to the standard. When this method is used, any difference in viscosity will be due to something other than differences in protein content. In running viscosity on the different flours from the mill by this method, I came to the conclusion that the ash content of the flour was playing fully as important a part in the viscosity reading as protein had ever done. Doctor Sasse and I then made up a solution of 27% magnesium phosphate, 20% calcium phosphate and 53% potassium phosphate and labeled it "Flour Ash". I found that I could take one of our high protein, short patent flours and add a small quantity of the "Flour Ash" solution and reduce the viscosity reading to nearly zero. This proved to my satisfaction that ash content of the flour is one of the biggest factors in determining viscosity.

I next took one of our best short patent flours and divided a sample of it. One-half of this sample was heated until all of the life was out of it; the other half remaining in first class condition as a check. Viscosity was run on these two samples and mixtures of different percentages of these two samples. Bread was baked from each sample upon which viscosity was determined. The dead flour could be detected in the bread when only 10% of the dead flour was in the blend. The viscosimeter would not detect the dead flour until the blend was very nearly 50% dead flour. Similar results were obtained by killing half of a sample by overbleaching it with chlorine gas. This shows that the viscosimeter will show flour quality but it is so crude and clumsy that it will not detect the fine differences that will be detected in the baking test.

My method of running viscosity is to take an amount of flour proportional to 10% protein equals 20 grams of flour and place it in a flask and add 100 c. c. of water. This mixture is shaken vigorously once every ten minutes for one hour, after which one-half c. c. of 50% lactic acid solution is added, shaken well and poured into the viscosimeter bowl and the motor turned on and the reading taken. This is called the first reading. Now add one c. c. of concentrated lactic acid to the solution in the bowl, unhook the plunger and stir the mixture for about 15 seconds, attach the plunger again, start motor and make a second reading. This second reading is the one generally given as the viscosity reading for the flour. After the second reading, I sometimes add a couple of drops of hydrogen peroxide, let stand about five minutes and spin for a third reading. I

find one or two drops of hydrogen peroxide is fully as effective as a cubic centimeter or more. I might add that we spin the bowl at thirty revolutions per minute instead of twenty as others do and we use a twenty-six wire instead of a thirty. These changes were made to get away from the pendulum effect in reading.

Our conclusion is that where one can get enough flour to make a baking test, it is time wasted to run a viscosity test or wash gluten. The protein and ash tests that are generally used in all cereal laboratories are far more accurate and can be made on less flour than the viscosity test. The viscosity test can be made much quicker than most other tests; but we believe that it means very little, if anything, when completed.

One of the biggest objections to the viscosity test is that there is no standard method of using it. Different methods and different wires make a world of difference in the reading. In other words, the personal element of the operator is bound to enter. The figures are worthless outside of the laboratory where made, except possibly to show a comparison of one flour with another and they mean very little unless checked with a baking test.

I do not know of a single laboratory in Kansas City that is using the viscosimeter and they are washing gluten only in cases where the flour sample is too small to bake.

I hope that this letter will give you some idea of what we have done and what we have found. If I can help you further, please let me know."

The Foster Gluten Test. The Foster gluten tester was used to study the gluten quality of eight of the Kanred x Hard Federation selections grown in 1928. The following procedure was used: two 20-gram samples of each kind of flour to be tested were weighed out and dough was made from each of them. They were then allowed to stand for 15 minutes in air, covered with water and allowed to stand

for 20 minutes. The gluten is then washed out and kept under water for 20 minutes. The pair of gluten masses are then placed in the tester, one in each cylinder, and baked at about 320 degrees F. for 30 minutes, removing weights from the rods when they seem to have reached their maximum height. At the end of 30 minutes, the tester is taken from the oven, measurements of the height of the gluten cylinders are made and another set of samples started. The tester which was used in these studies was very kindly loaned by Mr. Peter Toews of the Lyons Milling and Elevator Company, Lyons, Kansas.

The data on volume of gluten cylinders are given in Table XXXVIII. An examination of these results shows that large loaf volume and small gluten cylinders tend to be associated. The strains tested are arranged in order, those with the tallest gluten cylinders being listed first. The average loaf volume for the four samples with the largest cylinders is 1828 c.c., while the corresponding figure for the four samples with the smallest cylinders is 2005 c.c.; a difference of 177 c.c. in favor of the four samples with the shortest cylinders.

The gluten strength of some standard varieties grown in different parts of Kansas was also tested by means of the

Table XXXVIII. Foster gluten test, Kanred x Hard Federation selections

Mill number	Protein per cent	Height in m.m.			Start	Finish	Difference	Average difference	Baking test
		Start	Finish	Difference					
		Cylinder I.			:	Cylinder II.			
		C.G.							
12908	13.9	15	93	78	16	102	86	82	1875
12892	13.4	13	74	61	11	88	77	69	1650
12907	14.0	17	83	66	15	71	56	61	1845
12896	14.0	16	73	57	14	70	56	57	1940
12895	13.5	16	73	57	16	70	54	56	2190
12897	13.3	19	69	50	18	70	52	51	2000
12905	13.8	16	61	45	16	59	43	44	1800
12906	13.9	15	61	46	16	58	42	44	2030

Foster apparatus. The gluten cylinders obtained are shown in Plate VII. Turkey wheat made smaller gluten cylinders than Blackhull and Superhard. A large number of baking tests in which the K.S.A.C. high speed dough mixer has been used, almost invariably rank Turkey ahead of Blackhull and Superhard.

The Foster gluten test might be useful even though the "strong" wheats produce smaller gluten cylinders than the "weak" wheats, as was the case in the studies of standard varieties and the Karned x Hard Federation crosses, provided this inverse relation was consistent. Snyder (21) who used this test on a larger scale, and Mr. Toews, both found that the better quality wheats produced larger gluten cylinders than wheats of inferior baking quality.

Extensimeter Tests. The Chopin Extensimeter is one of the more recent attempts to measure gluten quality mechanically. This test has been used and explained by Chopin (8) and by Bailey and LeVesconte (1).

Two of the hybrid selections grown in the nursery in 1929 were tested on the extensimeter. These strains were selected on the basis of their baking performance, one having baked a poor loaf and one a good loaf.

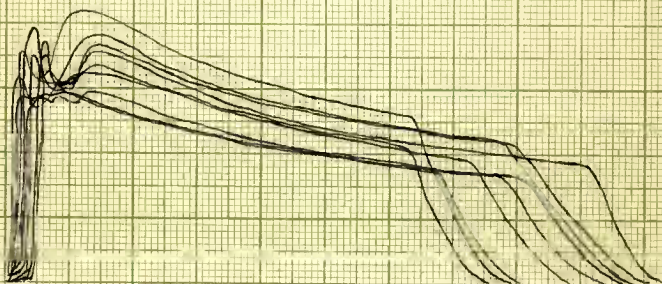
Plate VII . Gluten cylinders, Foster Gluten tester



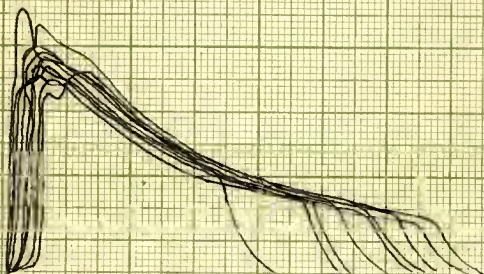
- |                             |                             |
|-----------------------------|-----------------------------|
| 1. Turkey, 9.2% protein     | 5. Blackhull, 9.7% protein  |
| 2. Turkey, 10.8% protein    | 6. Blackhull, 10.8% protein |
| 3. Turkey, 10.4% protein    | 7. Superhard, 10.2% protein |
| 4. Superhard, 10.8% protein | 8. Blackhull, 10.6% protein |

The following methods were used in conducting the extensimeter tests: Two hundred and fifty grams of flour were mixed with the amount of water considered correct for baking, as determined by the absorption test and by the feel of the dough. The flour and water were mixed in the high speed dough mixer for two minutes. The dough was worked in the hands to form a uniform ball. It was placed on a greased slab and rolled out to a uniform thickness. The dough was then covered with a damp cloth and a large boll jar. It was allowed to rest for 30 minutes and at the end of this period "biscuits" of 50 m. m. diameter were cut from the dough. These were used as soon as cut. The head of water on the extensimeter was maintained at a constant level, thus insuring uniform pressure. While these samples were being tested on the extensimeter they were identified only by number so as to eliminate the possibility of personal bias.

The purpose of conducting the test was to see if there was a correlation between the results secured on the extensimeter and those secured by the experimental baking method, using the K. S. A. C. high speed dough mixer. The curves shown in Figure 8 indicate that there is a significant correlation between extensimeter readings and loaf volume. The loaf volume of the "good loaf" sample 6el..#254529 was



Good Loaf



Poor Loaf

Fig. 8 Copied from Curves Obtained  
on the Chapin Extensimeter.

1920 c. c. while the volume of "poor loaf" sample Sel. No. 254981 was only 1700 c. c. This is a significant difference.

The sloping lines of the curves made with the selection which baked the poor loaf are concave, while those from the sample which baked the good loaf are more nearly straight.

#### SUMMARY AND CONCLUSIONS

Some of the results obtained with segregates from a cross of Kanred x Hard Federation are reported in this thesis. This cross was made at Chico, California, in 1920 by Mr. V. H. Florell, of the Office of Cereal Investigations, U. S. D. A., at the suggestion of Mr. J. A. Clark. The purpose in making the cross was to produce a winter wheat which would be earlier, stiffer strawed and higher yielding than Kanred and which would have the very acceptable milling and baking qualities of Kanred.

Hard Federation is a hard, white, spring wheat bred in Australia, which is early, stiff strawed and of course non-winterhardy. Kanred is a relatively late, hard, red winterhardy variety which has the weak straw characteristic of Turkey and other Crimean wheats.

In 1923, 1,580 plant selections in the  $F_3$  generation were grown. The number of selections has been constantly reduced and only twenty of the most promising strains were

planted in replicated row rows in the nursery in September, 1929. Six hybrid strains have been tested in plots at the Agronomy farm but only one was planted there in the fall of 1929. Early types appeared in the segregating generations of this cross. Many of these early types have been continued, and are being tested in the nursery at the present time.

The hybrid selections are from three to six days earlier in heading than the Kanred parent, on the average. Individual lines are now hand which head more than a week earlier than Kanred.

Observations on lodging of the Kanred x Hard Federation selections show that many of them have distinctly stiffer straw than Kanred. In the three-year period, 1927 to 1929, the hybrid selections lodged only 37 per cent, while Kanred lodged 59 per cent in the same tests.

The hybrids tested on the Salmon strength of straw apparatus were shown to have stronger straw than Kanred. On the average, it required .637 pound to break a straw of the hybrid selections while only .554 pound was required to break a straw of Kanred.

Segregation for cold resistance among  $F_3$  lines was distinct. Winter survival ranged from 0 to 80 per cent.

Artificial freezing trials conducted in the greenhouse showed that a few of the hybrid strains are about as winter-hardy as Kanred, but most of them are less cold resistant

than Kanred.

95

Extensive nursery tests for four years and less extensive plot tests for two years agree in showing that the hybrid selections have a marked advantage over Kanred in yield.

The higher yields of the hybrid strains are almost certainly due, in part at least, to their earliness. Selection on the basis of yield has been practiced throughout the period of testing. The lower yielding strains have been discarded, and the higher yielding lines continued in the nursery. A few of the most promising lines have been advanced to the plot tests at the Agronomy farm.

The hybrid selections have a slight advantage over Kanred in average test weight.

The kernel plumpness of the hybrids in the early generations was less, on the average, than the kernel plumpness of Kanred. The average plumpness of the hybrid strains has increased during the period of selection and is now superior to Kanred.

The hybrid selections which have been milled have a significant advantage, about two per cent, over Kanred in flour yield. This is to be expected since the crosses have a higher average test weight than Kanred.

The fact that these crosses have a higher average flour

yield than Kanred is of special significance, since Kanred produces higher flour yields than most other varieties of hard, red, winter wheat.

The average protein content of the hybrid lines is significantly lower, about one per cent, than that of the Kanred parent. A few individual hybrid lines are on hand which are equal or superior to Kanred in protein content. In view of the known negative correlation between protein content and yield and test weight, this is what should be expected, since the hybrid selections produce higher yields and have higher test weights than Kanred.

Quality of protein is as important as quantity. The hybrid selections, on the average, are not equal to Kanred in quality as shown by the experimental baking test. The hybrid selections, on the average, are not equal to Kanred, especially in loaf volume, though a few individual lines are equal to Kanred.

Attempts to differentiate gluten quality by washing were not successful. Considerable experience and skill are required on the part of the operator in order to obtain useful and significant results.

Viscosity determinations were made on a few samples, but the results were of little value in differentiating the

quality of the hybrid selections.

The Foster gluten test gave results which were not in accord with those obtained by Snyder and other chemists who have used this test. The taller gluten cylinders were obtained from flour samples which produced the smaller loaves; i. e., size of the Foster gluten cylinders and loaf volume were negatively correlated.

Results obtained with the Chopin Extensimeter agree very well with results of the experimental baking tests of the same samples. This is one of the newer mechanical tests of gluten quality and seems to offer considerable promise.

#### ACKNOWLEDGEMENTS

The writer wishes to express sincere appreciation to his major instructor, Dr. John H. Parker, for his kind assistance in connection with this thesis problem. Thanks are also due Dr. C. O. Swanson and Dr. Earl B. Working of the Department of Milling Industry for aid and suggestions in the quality studies. Thanks are due Professor S. C. Salmon for agronomic data from the farm plots, for data on strength of straw and for the results of the greenhouse freezing trials.

## LITERATURE CITED

1. Bailey, C. H., and LeVesconte, Amy, M.,  
1924. Physical tests of flour quality with the Chopin  
Extensimeter. Cereal Chemistry, 1:38-63.
2. Call, L. E., Green, R. M., and Swanson, C. O.,  
1925. How to grow and market high protein wheat.  
Kansas Agricultural Experiment Station,  
Circular 114.
3. Clark, J. A., Stephens, D. E., and Florell, V. H.,  
1920. Australian wheat varieties in the Pacific coast  
area. United States Department of Agriculture,  
Bulletin 877.
4. -----and Salmon, S. C.,  
1921. Kanred wheat. United States Department of  
Agriculture, Department Circular 194.
5. -----, Martin, J. H., and Ball, C. R.,  
1923. Classification of American wheat varieties.  
United States Department of Agriculture,  
Bulletin 1074.
6. -----, Florell, Victor H., and Hooker, John R.,  
1928. Inheritance of awniness, yield and quality in  
crosses between Bobs, Hard Federation and Propo  
wheats at Davis, California. United States  
Department of Agriculture, Technical Bulletin 39.
7. -----, and Quisenberry, Karl S.,  
1929. Inheritance of yield and protein content in  
crosses of Marquis and Kota spring wheats grown  
in Montana. Journal of Agricultural Research,  
38:205-217.
8. Chopin, Marcel.,  
1927. Determination of baking value of wheat by  
measures of specific energy of deformation of  
dough. Cereal Chemistry, 4:1-13.

9. Dill, D. B., and Alsberg, C. L.,  
1924. Some critical considerations of the gluten washing problem. *Cereal Chemistry*, 1:222-240.
10. Gericke, W. F.,  
1927. Why applications of nitrogen to land may cause either increase or decrease in the protein content of wheat. *Journal of Agricultural Research*, 35:133-139.
11. Hayes, H. K., and Amodeo, O. S.,  
1927. Inheritance of winterhardiness and growth habit in crosses of Marquis with Minhardi and Minturki wheats. *Journal of Agricultural Research*, 35:223-236.
12. -----, Immer, F. R., and Bailey, C. H.,  
1928. Correlation studies with diverse strains of spring and winter wheats, with particular reference to inheritance of quality. *Cereal Chemistry*, 6:85-96.
13. Pridham, J. T.,  
1916. The proportion of grain to straw in varieties of wheat. *Agricultural Gazette of N. S. Wales*, p. p. 230-231.
14. -----  
1920. Natural crossing in wheat. *Agricultural Gazette of N. S. Wales*, p. p. 457-461.
15. Quisenberry, Karl S., and Clark, J. Allen,  
1929. Breeding hard red winter wheats for winterhardiness and high yield. *United States Department of Agriculture, Technical Bulletin 136*.
16. Richardson, A. E. V.,  
1925. Wheat and its cultivation. *Department of Agriculture, Victoria, Australia, Bulletin 55*.
17. Salmon, S. C.,  
1910. Establishing Kenred wheat in Kansas. *Kansas Agricultural Experiment Station, Circular 74*.

18. Sewell, M. C., and Swanson, C. O.,  
1926. Tillage in relation to milling and baking qualities of wheat. Kansas Agricultural Experiment Station, Technical Bulletin 19.
19. Sharp, Paul Francis, and Gortner, Ross Aiken,  
1923. Viscosity as a measure of hydration capacity of wheat flour and its relation to baking strength. Minnesota Agricultural Experiment Station, Technical Bulletin 19.
20. Shollenberger, J. H., and Clark, J. Allen,  
1924. Milling and baking experiments with American wheat varieties. United States Department of Agriculture, Department Bulletin 1183.
21. Snyder, Harry,  
1904. Composition and bread making value of flour produced by roller process of milling. Annual Report Minnesota Agricultural Experiment Station, 199.
22. Swanson, C. O.,  
1925. The theory of colloid behavior in dough. Cereal Chemistry 2:265-275.
23. -----  
1928. Meaning of quality in wheat. Bulletin-- Association of Operative Millers, 257-262.